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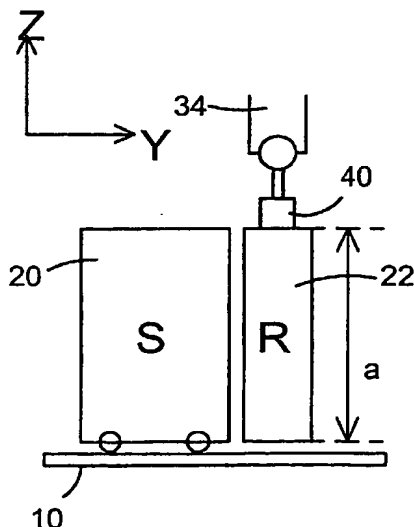
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(54) Title: ALIGNING OPTICAL COMPONENTS OF AN OPTICAL MEASURING SYSTEM



(57) Abstract: A measuring system for calibrating a machine in which a base (10) is attachable to a surface of the machine and a housing (20) is mountable on the base, wherein at least one surface of the base and at least one surface of the housing are each provided with a complementary part of a mounting device, such that when the two parts of the mounting device are connected together, the housing may be aligned in any of a plurality of predetermined directions. The base includes a lifting mechanism (64) which when lowered allows the complementary parts of the mounting device (93, 95) of the housing (20) and the base (10) to be in contact and when raised causes them to at least partly break contact with one another. The level of the base (10) may be adjusted using a system of balls and tapered rollers.

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ALIGNING OPTICAL COMPONENTS OF AN OPTICAL MEASURING  
SYSTEM.

The present invention relates to a method of and  
5 apparatus for aligning the components of an optical  
measuring system preparatory to using them in a  
measuring operation.

One known type of optical measuring system consists of  
10 two or more housings, at least one of which is to be  
fixed to the bed of the machine and another one of  
which is to be carried by the arm or spindle of the  
machine. Either one or both of the machine bed and  
machine spindle is movable. One of the housings  
15 contains one or more light sources and detectors, and  
will be referred to hereinafter as the "source housing"  
while the other housing contains reflectors, and will  
be referred to hereinafter as the "reflector housing".  
Usually the source housing is maintained in a fixed  
20 position on the bed of the machine and the reflector  
housing is mounted on a part of the machine moveable  
with respect to the machine bed e.g. the machine  
spindle.

25 Aligning the optical components is often a time-  
consuming process which involves firstly the alignment  
of the source housing so that the beam or beams  
generated are directed along, or parallel to, one or  
more of the X,Y and Z axes of the machine. Then the  
30 reflectors have to be aligned with the beam or beams so  
that the reflected beams are directed back onto the  
detectors. Depending on the type of detectors being  
used the alignment may have to be accurate to within a  
few arc seconds.

A first aspect of the invention provides a measuring system for calibrating a machine, the measuring system comprising:

- a base attachable to a surface of the machine;
- 5 a housing mountable on the base;
- wherein at least one surface of the base and at least one surface of the housing are each provided with a complementary part of a mounting device, such that when the two parts of the mounting device are connected
- 10 together, the housing may be aligned in any of a plurality of predetermined directions.

Preferably the measuring system has at least two housings, comprising:

- 15 a base attachable to a first surface of the machine on which a first housing may be mounted;
- a second housing attachable to a second surface on the machine, said first and second surfaces of the machine being moveable relative to one another;
- 20 said first and second housings each being provided with a complementary part of a first mounting device, such that when the two parts of the first mounting device are connected together, the housings are mutually aligned;
- 25 wherein at least one surface of the base and at least one surface of the first housing are each provided with a complementary part of a second mounting device, such that when the two parts of the second mounting device are connected together, the first and
- 30 second housings may be aligned in any of a plurality of predetermined directions.

The complementary parts of the second mounting device may comprise a set of cooperating elements on the base

and the first housing. A subset of cooperating elements used to align the first housing in a first direction may also form a subset of cooperating elements used to align the first housing in a second direction.

5

Preferably the second housing is mounted onto the second surface of the machine via a connecting device and wherein a plurality of surfaces on the second housing and at least one surface on the connecting  
10 device are each provided with a complementary part of a third mounting device, such that the second housing may be attached to the connecting device when orientated in any of the plurality of predetermined directions

15 The complementary parts of the third mounting device may be arranged such that once the first and second housings have been aligned using the first mounting device, and the first housing and base have been aligned using the second mounting device, the second  
20 housing and the connecting device may be connected without realignment of the first and second housing relative to one another being required.

Preferably the geometric combination of the first and  
25 second housings and the connecting device is such that the axes along which the first and second housings may be aligned intercept at a common point. This may be such that the housing mounted on the moving part of the machine starts in the same position in X,Y and Z  
30 whatever the orientation of the first and second housings. Alternatively it may be such that the housing mounted on the moving part of the machine is moved through the common point of interception, whatever the orientation of the first and second

housings.

A cable leads to the first housing and the cable may be provided with a cable mounting device, and the at least  
5 one surface on the cable mounting device and a plurality of surfaces on the base are each provided with complementary parts of a fourth mounting device such that the cable mounting device may be mounted on the base at different locations such that at each  
10 orientation of the first housing, the cable transmits an equal force on the housing. The cable mounting device may be provided with a plurality of angled faces, wherein two or more faces of the cable mounting device are provided with said complementary part of the  
15 fourth mounting device, such that different faces of the cable mounting device may be attached to base for different orientations of the first housing, such that the cable transmits an equal force on the housing for each orientation of the housing.

20

A second aspect of the invention provides a platform for supporting a housing, the housing and platform being provided with complementary parts of a mounting device which define the position of the housing when  
25 mounted on the platform, comprising:

a fixed surface of the platform on which the housing may be supported and on which part of said mounting device is located;

a lifting mechanism moveable between upper and  
30 lower positions relative to said fixed surface;

whereby in its lower position, the lifting mechanism allows the complementary parts of the mounting device of the housing and the fixed surface to be in contact with one another and in its upper

position, the lifting mechanism causes the complementary parts of the mounting device of the housing and the fixed surface to at least partly break contact with one another.

5

Preferably the lifting mechanism comprises a movable surface of the platform which may be raised and lowered;

whereby when the housing is placed on the moveable surface of the platform, the moveable surface may be lowered to place the housing onto the fixed surface such that the complementary parts of the mounting device are connected or raised to disconnect the complementary parts of the mounting device.

15

The movable surface and the housing may be provided with complementary parts of a second mounting device such that the complementary parts of the first mounting device on the housing and fixed surface are thereby pre-aligned.

20

In a first embodiment, rotation of the movable surface in a first direction causes said movable surface to be raised and wherein rotation of the movable surface in a second opposite direction causes said movable surface to be lowered.

25

In a second embodiment the movable surface is mounted on a spring whereby rotation of a cam raises or lowers the spring and thus the movable surface.

30

A third aspect of the invention provides apparatus for adjusting the angle of an object about an axis mounted on a surface comprising:

an upper plate onto which the object is mounted and a lower plate which in turn is mounted onto the surface;

5 a track located on the inner surface of one of the upper and lower plates;

a ball located between the upper and lower plates, the ball being in contact with the at least one track in the upper or lower plates;

10 wherein the track is arranged such that when the ball is moved in a first direction, the ball is raised and causes the plates to move apart and wherein when the ball is moved in a second opposite direction, the ball is lowered and causes the plates to move together.

15 The track may comprise a pair of non-parallel rollers. Alternatively, the track may comprise a pair of parallel rollers which are positioned at an angle from the plane of the upper or lower plate in which they are located, or a pair of rollers and wherein each roller  
20 in the pair of rollers is tapered.

Preferably the other of the upper and lower plates is provided with at least one element which is in contact with the ball. The at least one element may comprise a  
25 pair of parallel rollers. Alternatively, the at least one element may comprise a plane surface.

Preferably one of the at least one element and the track in the upper plate is part of a mount for the  
30 object and the other of the track and the at least one element of the lower plate is part of a mount for the surface, thereby forming a direct path from the object to the surface through the tracks, balls and elements.



In a preferred embodiment, several sets of balls and tracks are provided so that the angle of the upper plate may be adjusted about several axes. In addition, a track and ball may be provided between adjacent  
5 substantially vertical surfaces of the upper and lower plates such that the upper plate may be rotated about the axis perpendicular to the plane of the lower plate.

Preferably the apparatus is provided with at least two  
10 tracks and balls to adjust the angle of the upper plate relative to the plane of the lower plate and one track and ball to adjust the angle of the upper plate about the axis perpendicular to the plane of the lower plate, wherein the tracks used to adjust the angle of the  
15 upper plate relative to the plane of the lower plate are located in the lower plate so that during rotation of the upper plate, the elements in the upper plate may slide or rotate over the balls and thereby allow the upper plate to be rotated independently of the  
20 adjustment of the angle of the upper plate relative to the plane of the lower plate.

Two sets of tracks and rollers and a pivot may be provided to allow adjustment of the angle of the upper  
25 plate relative to the plane of the lower plate. In addition, a third set of track and roller may be provided to provide rotation of the upper plate about an axis perpendicular to the plane of the lower plate.

30 Three sets of tracks and rollers may be provided to allow adjustment of the angle of the upper plate relative to the plane of the lower plate and in addition allow adjustment of the height of the upper plate relative to the lower plate. A fourth set of

tracks and rollers may be provided to provide rotation of the upper plate about an axis perpendicular to the plane of the lower plate.

5 The invention will now be described, by way of example only, and with reference to the following drawings in which:

Fig 1 is a diagrammatic elevation of the component of a prior art optical measuring system;

10 Fig 2 is a side view of an adjustable connector according to the invention;

Figs 3A-3E are views of the source and reflector housings aligned along the X,Y,-X,-Y and Z axis directions;

15 Figs 4A and 4B show the geometric combination of the source and reflector housings aligned along the Y and Z directions;

Figs 4C and 4D illustrate the interception of axes for different orientations of the housings;

20 Fig 4E illustrates the errors along the X direction for fig 4D;

Fig 5A is a plan view of the optical measuring system aligned with the Z axis;

25 Fig 5B is a side view of the optical measuring system aligned with the Z axis;

Fig 5C is a plan view of the optical measuring system aligned with the X axis;

Fig 5D is a side view of the optical measuring system aligned with the X axis;

30 Figs 6A and 6B show plan and side views of a first embodiment of the controlled lowering platform;

Figs 6C and 6D show plan and side views of a second embodiment of the controlled lowering platform;

Figs 6E-6G show plan, side and perspective views

of a third embodiment of the controlled lowering platform;

Fig 6H illustrates a side view of the controlled lowering platform;

5 Figs 7-9 illustrate plan, side and perspective views of the base plate;

Fig 10 is a cross section of the first tilt adjustment device;

10 Fig 11 is a cross section of the second tilt adjustment device;

Fig 12 is a cross section of the third location;

Fig 13 is a cross section of the rotation adjustment device;

15 Fig 14 is a schematic illustration of relative movement of the upper plate of the base plate;

Fig 15 is a plan and side view of non-parallel rollers;

Fig 16 is a plan and side view of parallel angled rollers;

20 Fig 17 is a plan and side view of tapered rollers;

Fig 18 is a plan view of a biasing spring used in the base plate of Figs 7-9;

Fig 19 is a side view of the biasing spring of Fig 18;

25 Fig 20 is a perspective view of the biasing spring of fig 18; and

Fig 21 is a schematic illustration of the arrangement of kinematic elements in a prior art base plate.

30

Referring to the drawings, Fig 1 shows a prior art embodiment of an optical measuring system for mounting on a machine as disclosed in co-pending application PCT/GB01/03096 filed on 11<sup>th</sup> July 2001.

The optical measuring system includes a base plate 10, a source housing 20 and a reflector housing 22, all of which need to be properly aligned with one or more of the machine axes. The base plate 10 is connected to the bed of the machine by screws 12, 14.

The source housing 20 may contain an autocollimator formed in optical sequence by, a light source 24, a beam splitter 26, a collimating lens 28 through which a collimated light beam passes out of the housing, and a detector 30 which receives a return light beam from the reflector 32 in the reflector housing 22 via the beam splitter 26.

The source housing 20 also includes a kinematic seat in the form of three cooperating pairs of male and female elements, for example a ball and V-groove 16, suitably spaced and arranged in a triangular array, for example spaced at 120° apart. The seating elements 16 cooperate with three V - shaped grooves (not shown) on the base plate to form a conventional kinematic seat for repeatable positioning of the housing on the base plate.

The source housing has a further kinematic seat 18 on its front face (i.e. the face which is orthogonal to the beam direction) on which the reflector housing may be seated. The light source and the reflector are aligned during the manufacturing stage to ensure that when the reflector housing is seated in the kinematic seat 18 on the front face of the housing, the light beam and reflector are properly aligned.

It can be seen therefore that once the source housing

20 is correctly aligned to direct a light beam along one of the machine axes, eg the X-axis, the reflector housing 22 can be seated on the kinematic seat 18 on the front face of the source housing 20, and will  
5 automatically be aligned with the beam from the light source 24. Magnets 33 may be used to urge the two housings 20,22 together at the kinematic seat 18.

In order to take care of any mis-match in position  
10 between the machine spindle 34 and the reflector housing 22 when the two are to be connected together, the reflector housing 22 is provided with a limited amount of compliance by using an adjustable connector by means of which the housing 22 can be connected to  
15 the spindle 34 of the machine. The adjustable connector has a ball 36 which is to be seated in a socket 38 on the machine spindle. The ball 36 is adjustably supported in a retaining device 40 which, in turn is connected to the reflector housing 22, by any  
20 suitable means.

A preferred embodiment of the adjustable connector will now be described with reference to Fig 2. The socket 38 of the machine spindle comprises a cylindrical bore  
25 which houses ball 36 of the adjustable connector. The retaining device 40 also comprises a cylindrical bore 42 and is mounted on the reflector housing 22, preferably by kinematic mounts 52.

30 The ball 36 of the adjustable connector is connected by a stem 46 to a further ball 48 which lies inside the bore 42 of the retaining device 40.

The Balls 36 and 48 of the adjustable connector may

only have a part spherical surface at the portion of the ball in contact with the surface of the cylindrical bore.

- 5 The ball 36 can be adjusted through a limited angle to enable it to be engaged in the socket 38 of the machine spindle. The ball is retained in socket 38 in known manner by providing magnets (not shown) in the ball 36, the socket 38, or both.

10

- Two slits 54,56 extends from opposite ends of the adjustable connector along its longitudinal axis to just short of its centre, leaving just a small bridging portion 57 connecting the two halves of the adjustable connector together. A locking screw 58 is provided in 15 the socket 38 of the machine spindle which when tightened pushes against the ball 36, thus fixing the ball 36 within the socket 38 and also pushing the two halves of the ball 36 together. The bridging portion 20 57 of the adjustable connector acts as a hinge and as the two halves of ball 36 are pushed together, the two halves of ball 48 are pushed apart and against the sides of the cylindrical bore 42, fixing it in position.

25

This connector thus has the advantage that one actuation locks both balls.

- Once the source housing 20 has been aligned with an 30 axis of the machine, the reflector housing 22 attached to the machine spindle can be brought up to the source housing 20. With the locking screw loosened, the adjustable connector will be free enough to rotate so that the reflector housing 22 will seat in the

kinematic seat 18. By this means automatic alignment of the source housing 20 and the reflector housing 22 can be ensured. Once seated in the kinematic seat 18 the locking screw is tightened to maintain the  
5 orientation of the housing 22.

It is desirable to align the source housing 20 with other machine axes. In the above-described example, where the source housing is mounted on a base plate,  
10 the source housing may have other sets of kinematic elements on its lower surface or on other ones of its orthogonal faces. By this means it can be rotated through 90 ° in different planes and be re-seated on the kinematic seat on the base plate in different  
15 orientations with the light beam from the source directed along different ones of the machine axes. The reflector housing will continue to seat in the same kinematic seat 18 on the source housing so that it will also be aligned with the different axes.

20 Figs 3A-D show the plan view of the source housing 20 and reflector housing 22 on the base plate 10. Fig 3a shows the light beam aligned with the X axis, Fig 3b shows the light beam aligned with the Y axis, Fig 3c  
25 shows the light beam aligned with the -X axis and Fig 3d shows the light beam aligned with the -Y axis. Fig 3e shows a side view with the light beam aligned with the Z axis.

30 A set of kinematics elements are provided on the base plate and source housing to define each of the X, Y, Z, -X, -Y directions. Each set of kinematics are not necessarily independent, with balls and rollers or V-shaped grooves from one set also forming part of

another set.

Alternatively a block in the form of a cube or a cuboid may be used instead of a base plate. Such a block  
5 would be provided with kinematic seats on various ones of its orthogonal faces so that, by using a single kinematic seat on the source housing, it can be oriented in different directions by engaging its kinematic seat with any one of those on the block.  
10 Also in this case the reflector housing will continue to use the same kinematic seat on the source housing.

For each orientation of the source and reflector  
15 housing 20,22, the reflector housing 22 must be mounted on the retaining device 40 of the adjustable connector in a different position. The location of the reflector housing 22 on the retaining device 40 for each orientation is defined by a respective kinematic seat.  
20 A different set of kinematic elements is thus provided between the reflector housing 22 and the retaining device 40 for each orientation of the reflector housing. As before, each set of kinematics may share elements with another set. This enables the orientation  
25 of the reflector housing 22 to be changed without adjustment of the adjustable connector in the machine spindle.

Once the source and reflector housings 20,22 have been  
30 aligned for the first axis using the kinematic seat 18, the orientations of the kinematic elements between the source housing 20 and the base plate 10 and between the reflector housing 22 and the retaining device 40 means that for subsequent axes, realignment of the source and



reflector housings 20,22 on the kinematic seat 18 is not required.

For calibration of large machines, it is desirable to  
5 start with the source housing 20 in the middle of the machine and first move the reflector housing 22 along one axis (e.g. X axis) and then turn the source and reflector housings 20, 22 around 180° and move the reflector housing along that axis in the opposite  
10 direction (e.g. -X axis). It is thus desirable for the source housing 20 and base plate 10 to have kinematics defining the -X and -Y directions.

There are thus five sets of kinematics between the  
15 source housing 20 and the base plate 10 and between the reflector housing 22 and the retaining device 40 defining the X,Y,Z,-X and -Y directions, although each set is not necessarily independent from the other sets.

20 As illustrated in Figs 4A and 4B, the geometric combination of the source housing 20 and the reflector housing 22 allow the same co-ordinate start position for calibration of x,y and z axis after initial set up.

25 Fig 4A shows the source housing 20 being aligned along the Y axis and fig 4B shows the source housing 20 aligned along the Z axis. In both cases the distance a between the quill 34 and the reflector housing 22 is the same. Thus when calibrating in different  
30 orientations (i.e. along the X,Y or Z axes), the start point is always the same.

As illustrated in Fig 4C, the geometric combination of the source housing 20 and the reflector housing 22 is

such that there is an interception of the axes (X,Y,Z) along which the source and reflector housings are to be aligned. Preferably the co-ordinate start position is at this interception O (as described above). However  
5 it is also possible to have non-common start positions,  $a_1, b_1, c_1$  for each orientation, as long as there is an interception of the axes and the distance  $x_a, x_b, x_c$  between each start point  $a_1, b_1, c_1$  and the interception O is known. (Although these distances do not need to be  
10 known accurately). In this case, it is preferable that the start points are on the far side of the interception from the direction of travel, as illustrated in Fig 4C, as this results in no loss of information during movement of the reflector housing.  
15 As illustrated in Fig 4D, this would not be the case if the start positions  $a_2, b_2, c_2$  are on the other side of the interception O as there will be no data between the interception and the start positions  $a_2, b_2, c_2$  which will introduce errors. Fig 4E shows the measurement  
20 data along the X axis for the arrangement of fig 4D. There is no information between the origin O and the start point  $a_2$ .

The optical source may be located remotely from the  
25 source housing, particularly as heat from the optical source may cause distortion on the housing. An optical fibre may thus be used to channel the light from the light source to the source housing.

30 The source housing is provided with a supply cable which houses the optical fibres, electrical signals and supplies. This is shown in Figs 5A-D. Figs 5A and 5B show the plan and side view respectively of the source housing 20 aligned with the Z axis. Figs 5C and 5D

show the plan and side view respectively of the source housing aligned with the X axis. The supply cable 60 transmits forces due to its bending onto the source housing 20 which may result in the source housing not sitting squarely on the kinematic seat 16. It is therefore desirable to minimise the force due to the bending of the cable 60.

The supply cable 60 is provided with a cable mounting block 62 which may be attached to the base plate 10. The mounting block can be clipped into various locations on the base plate 10 depending upon the orientation of the source housing 20. The position of the cable mounting block 62 on the base plate is defined by a location seat which could be kinematic and is held in position by magnets (not shown).

The cable mounting block 62 has a plurality of angled faces, such that in different orientations of the source housing 20, different faces of the cable mounting block may be clipped onto the base plate 10, by way of a respective seat, e.g. kinematic seat on that face.

The position of the location seats and the angles of the faces of the cable mounting block 62 ensures that minimal and equal forces from the cable are transmitted to the source housing for each orientation of the source housing.

In the present embodiment the base plate is provided with a controlled lowering platform so that the source block is lowered onto the kinematics in controlled way. Use of a controlled lowering platform has the advantage

that the source housing is gently lowered onto the kinematics ensuring an accurate repeatable location. It also minimises damage to the kinematic elements.

5 Fig 6A shows a first embodiment of the controlled lowering platform. A lifting platform 64 is provided onto which the source housing 20 may be placed. This is separated from the base plate by a rotatable disc 66. Ball bearings 68 are located between the disc 66  
10 and the base plate 10 and between the disc 66 and the lifting platform 64 to allow rotation of the disc 66. The surface of the disc 66 is provided with tapered grooves into which the ball bearings 68 are seated. When the ball bearings are seated in the wide portion  
15 of the groove, the lifting platform 64 is in its lowered position. However as the disc 66 is rotated, the groove presents its narrower portion to the ball bearing 68 resulting in the lifting platform 64 being raised. By moving the disc 66 in the opposite  
20 direction, the lifting platform 64 may gently be lowered.

A damper 70 is provided to smooth the movement of the lifting platform 64. The damper 70 may be provided on  
25 a lever 72 which is used to rotate the disc 66. Alternatively the damper 70 may be located between the base plate 10 and the lifting platform 64, as shown in Fig 6B.

30 A second embodiment of the controlled lowering platform is illustrated in Figs 6C and 6D. In this embodiment, the lifting platform 64 is provided with a downwardly dependent cylinder 74 with a threaded outer surface. The central disc is replaced by a ring 76 with a

threaded inner surface. Rotation of the ring 76, using the lever 72 will result in the lifting platform 64 being raised by rotation in one direction and the lifting platform being lowered in the opposite  
5 direction.

As in the previous embodiment, a damper 70 may be provided on the lever 72 as shown in Fig 6C or between the base plate 10 and the lifting platform 64, as shown  
10 in fig 6D.

A third embodiment of the controlled lowering platform is illustrated in Figs 6E, 6F and 6G. In this embodiment the lifting platform 64 is supported by a  
15 pair of parallel springs 80, 82. Both springs 80, 82 are connected to a fixed part of the platform (not shown) at points 84, 86, 88 on their outer surfaces and to the moveable platform 64 at their inner surfaces.

20 A rod 88 is provided with a cam 94 at one end which abuts the upper spring 80 and a lever 96 at its other end. The rod 88 is rotatable about bearings 90, 92 in the fixed surface of the platform (not shown). Rotation of the lever 96 causes rotation of the rod 88  
25 and cam 94. As the cam 94 abuts the upper spring 80, it raises or lowers the inner surface of the upper spring 80 as it rotates and thereby also raises and lowers the lifting platform 64 which is attached to the inner surface of the spring 80.

30

Use of a pair of parallel springs 80, 82 results in parallel movement of the lifting platform 64, so that even though the cam is located on one side of the spring 80, the lifting platform 64 is raised and

lowered without tilting.

In all three embodiments, whether the lifting platform has a rotational or linear movement, the mechanisms  
5 allow the movement of the lifting platform to be highly repeatable so that each time the source housing is lowered onto the kinematics, it is lowered accurately to the same position.

10 The lifting platform of the controlled lowering platform may also be provided with a set of location elements 97, with a corresponding set of location elements 98 on the source housing 20, as illustrated in Fig 6H. These location elements 97,98 act to correctly  
15 position the source housing 20 on the lifting platform 64 so that when the platform 64 is lowered, the kinematic elements 93 on the source housing 20 are pre-aligned with kinematic elements 95 on the base plate 10 and the source housing 20 may therefore be lowered  
20 correctly onto the base plate kinematics. These location elements 97,98 on the lifting platform 94 and source housing 20 may be less accurate than the location kinematics 93,95 between the source housing 20 and base plate 10. The location elements 97,98 on the  
25 source housing and lifting platform thereby receive most of the wear and thus protect the kinematic elements 93,95 on the source housing 20 and base plate 10.

30 As described earlier, the source housing is mounted on a base plate which is in turn mounted onto the machine table. The base plate must be aligned with the X-Y plane and this is normally achieved by mounting it on an accurately horizontal machine bed. However if the

machine bed is not accurately horizontal, then adjustment of the base plate is required.

5 Figs 7 to 20 illustrate a base plate provided with an adjustment mechanism which allows for tilt adjustment about both X and Y axes and rotation about the Z axis. The adjustable base plate will now be described in more detail with reference to these figures.

10 Figs 7,8 and 9 show top, side and perspective views of the base plate 10 respectively. The base plate comprises a lower plate 110 and an upper plate 112 which is moveable relative to the lower plate. The upper and lower plates may be connected by means (not  
15 shown) which allow relative movement between them, such as magnetic or spring means.

First and second tilt adjusters 100,102 are provided on the base plate to enable adjustment of the tilt of the  
20 upper plate about the X and Y axes respectively. Fig 10 shows a cross section of the first tilt adjuster 100. A pair of rollers 114, 116 is provided in the upper plate 112 and a pair of rollers 118, 120 is provided in the lower plate 110. A ball 122 is located  
25 between the upper and lower plates and is in contact with both pairs of rollers. The pair of rollers 114, 116 located in the upper plate 112 are parallel to one another. However the pair of rollers 118, 120 located in the lower plate 110 are non parallel. If the ball  
30 122 is moved along the rollers 118, 120 towards the narrower end, the ball 122 will be pushed upwards and will in turn push the upper plate 112 upwards. If the ball 122 is moved in the opposite direction towards the wider end, the ball 122 will be lowered and in turn the

upper plate 112 will be lowered. As shown in figs 7 and 9, an adjustment screw 124 is provided to alter the position of the ball 122 within the first adjustment device 100.

5

As shown in Fig 10, the pair of rollers 114, 116 in the upper plate 112 provide a kinematic seating for a kinematic element 128 of the source housing 20 and an element 130 is located in contact with and in a fixed position relative to the pair of rollers 118, 120 in the lower plate 110 to connect with the machine table 11.

Fig 11 shows a cross section of the second tilt adjuster 102. As before, each of the upper and lower plates 112, 110 is provided with a pair of rollers 214, 216 and 218, 220 respectively, which locates kinematic elements 228 and 230 in contact with the source housing 20 and machine table 11 respectively. As before, element 230 is in contact with and in a fixed position relative to rollers 218, 220. However, the second tilt adjuster 102 differs from the first 100 in that a plate 232 is provided beneath the pair of parallel rollers 214, 216 in the upper plate 112. The ball 222 between the upper and lower plates 112, 110 is thus in contact with the pair of rollers 218, 220 beneath it and the plate 232 above it. As before, adjustment of the position of ball 222 using the adjustment screw 126 raises or lowers the upper plate 112 directly above it.

30

At a third location 104, another ball 322 is provided between the upper and lower plates 112, 110 sandwiched between upper and lower pairs of rollers. Fig 12 shows a cross section of this arrangement. As before both of



- the upper and lower plates 110, 112 are provided with a pair of rollers, 314, 316 and 318, 320 respectively, and the ball 322 is in contact with both pairs of rollers. Ball 322 is in a fixed position with respect to rollers 314, 316 and ball 220 is in a fixed position with respect to rollers 318, 320. In this case both pairs of rollers are parallel and the ball 322 is not provided with an adjustment screw.
- 10 To adjust the tilt of the base plate 10 about the X axis, the adjustment screw 124 of the first tilt adjuster 100 is turned. This will either push the ball 122 and thus the upper plate 112 upwards or downwards, depending on the direction it is turned. As the
- 15 adjustment screw 124 of the first tilt adjuster 100 is turned, the upper plate 112 will pivot about the ball 222 of the second tilt adjuster 102 and the ball 322 in the third location 104.
- 20 To adjust the tilt of the base plate 10 about the Y axis, the adjustment screw 126 of the second tilt adjuster 102 is turned. As described above, this will either push the ball 222 and thus the upper plate 110 upwards or downwards. As the adjustment screw 126 of
- 25 the second tilt adjuster 102 is turned, the upper plate 110 will pivot about the ball 122 of the first tilt adjuster 100 and the ball 322 in the third location 104.
- 30 The base plate 10 also enables rotation of its upper plate 112 about the Z axis. A rotation adjustment device 106 is provided for this purpose. A cross section of the rotation adjustment device 106 is shown in Fig 13.

At the rotation adjustment device 106, the upper plate 112 is provided with a cut out 140 and a portion 142 of the lower plate 110 extends upwards into the space provided by the cut out 140. In this manner the upper and lower plates 112, 110 are provided with adjacent substantially vertical walls 144, 146. As shown in Fig 13, the substantially vertical wall 144 of the lower plate 110 is provided with a pair of rollers 150, 152. The substantially vertical wall 146 of the upper plate 112 is provided with a plate 154. A ball 156 is in contact with both the pair of rollers 150, 152 and the plate 154. As in the first and second tilt adjusters 100, 102, the rollers 150, 152 are not parallel. If the ball 156 is moved along the rollers 150, 152 towards the narrower end, the ball 156 will be pushed away from the wall 144 of the lower plate 110 and will in turn push away the wall 146 of the upper plate 112. The upper plate 112 is thereby rotated relative to the lower plate 110. By moving the ball 156 in the opposite direction, i.e. towards the wider end, the upper plate 112 will rotate relative to the lower plate 110 in the opposite direction. As before, an adjustment screw 127 is used to alter the position of the ball 156 on the rollers 150, 152.

When the upper plate 112 is rotated, it interacts with the balls and rollers in the first and second tilt adjustment devices 100, 102 and the third location 104 in the following way. At the first tilt adjustment device 100, the parallel rollers 114, 116 in the upper plate 112 may slide over the ball 122 in the direction of the nominal centre line of the rollers, or may rotate about the ball 122. At the second tilt

adjustment device 102, the plate 232 of the upper plate 112 slides over the ball 222 and therefore does not constrain rotational movement of the upper plate 112. At the third location 104, parallel rollers 314, 316 in  
5 the upper plate slide over the ball 322 in the direction of the nominal centre line of the rollers or the rollers rotate about the ball 322. Fig 14 shows the movement of the upper plate 112 about each of the balls 122, 222, 322 of the first and second tilt  
10 adjustment devices 100, 102 and the third location 104 during rotation.

As the balls 122, 222 of the first and second tilt adjustment devices 100, 102 remain stationary with respect to the rollers 118, 120, 218, 220 in the lower  
15 plate 110 and ball 322 of the third location 104 remains stationary with respect to the rollers 314, 316 in the upper plate 112, rotation of the upper plate 112 has no effect on the tilt adjustment of the upper plate.

20 In the above embodiment, the rollers 118, 120 in the lower plate 110 of the first and second tilt adjustment devices 100, 102 and the rollers 150, 152 of the rotation adjustment device 106 are non parallel such  
25 that one end of each pair is closer together than the other end. This causes the ball as it is moved along the rollers to be raised as it approaches the ends closer together or to be lowered as it approaches the ends further apart.

30 By varying the angle of the rollers about their nominal centre line, it is possible to vary the amount of the height lift of the ball for a given distance travelled along the rollers. This has the advantage that it is

therefore possible to adjust the sensitivity of the base plate by altering the angle of the rollers.

Fig 15 shows a plan view of the non-parallel rollers 118, 120. This effect can be achieved by alternative means, for example as shown in Fig 16, parallel rollers 160, 162 are set at an angle from the lower plate 110, so that the ball 164 is moved up and down a slope as it is moved along the rollers. Fig 17 shows a pair of tapered parallel rollers 164, 166 with one end of each roller being wider than the other end.

In an alternative embodiment of the invention, the ball 322 and pairs of parallel rollers 314, 316, 318, 320 located at the third location 104 are replaced with an additional tilt adjustment device, of the same type as the first tilt adjustment device. This enables the height of the upper plate 112 along the Z axis to be altered, as now the height can be individually adjusted about all three tilt adjustment points.

20

In each of the tilt adjustment devices and the rotation adjustment device, the balls are biased towards the adjustment device. Figs 18, 19 and 20 illustrates the plan, end and perspective views respectively of a spring used to bias the ball towards the adjustment device. The spring 170 comprises a slide 172 which is located between the upper and lower plates 112, 110. A surrounding plate 174 is provided which defines the boundaries of movement of the slide 172. The surrounding plate is attached to the bottom of the upper plate 112. Both the slide 172 and surrounding plate 174 may be made by a chemi-etch process from the same sheet which ensures that they are the same thickness. This ensures good tolerances which provides

a good slide mechanism.

One end of the slide 174 is provided with three tabs 176,178,180. One of the tabs 180 protrudes upwards  
5 from the middle of the end of the slide 174 and abuts a ball 182 of an adjustment device. The remaining two tabs 176,178 protrudes downwards from either side of the end of the slide 174 and abut springs 184,186 located in channels 188,190 in the upper plate 112. The  
10 springs 184,186 extend between one end of the channels 188, 190 and the protruding tabs 176,178 and thereby exert a force to bias the slide 172 towards the adjustment device 192. As the slide 172 is pushed towards the adjustment device 192 by the springs 184,  
15 186, the tab 180 pushes the ball 182 towards the adjustment device 192.

An advantage of the adjustable base plate of the present invention is that the balls and rollers are in-  
20 line between the table, base plate and source housing, i.e. there is a direct path through the kinematic elements. For example, as shown in fig 10, the first tilt adjustment device 100 has a direct path from source housing 20 through kinematic element 128,  
25 rollers 114,116, ball 112, rollers 118,120, element 130 to table 11. As shown in Fig 11, the second tilt adjustment device 102 has a direct path from source housing 20 through kinematic element 228, rollers 214,216, plate 232, ball 222, rollers 218, 220, element  
30 230 to table 11. Fig 21 illustrates a prior art arrangement in which the kinematics between each part are offset. This has the disadvantage that any distortion of the base plate, e.g. due to thermal bowing, will cause a lever effect on the housing. In

the present invention with a direct path through the balls and rollers, distortion of the plate has no effect on the position of the housing. The balls and rollers are made of a hard material such as steel or  
5 tungsten carbide.

## CLAIMS

1. A measuring system for calibrating a machine, the measuring system comprising:
- 5 a base attachable to a surface of the machine;  
a housing mountable on the base;  
wherein at least one surface of the base and at least one surface of the housing are each provided with a complementary part of a mounting device, such that
- 10 when the two parts of the mounting device are connected together, the housing may be aligned in any of a plurality of predetermined directions.
2. A measuring system for calibrating a machine
- 15 according to claim 1, the measuring system having at least two housings, comprising:
- a base attachable to a first surface of the machine on which a first housing may be mounted;  
a second housing attachable to a second surface on
- 20 the machine, said first and second surfaces of the machine being moveable relative to one another;  
said first and second housings each being provided with a complementary part of a first mounting device, such that when the two parts of the first mounting
- 25 device are connected together, the housings are mutually aligned;
- wherein at least one surface of the base and at least one surface of the first housing are each provided with a complementary part of a second mounting
- 30 device, such that when the two parts of the second mounting device are connected together, the first and second housings may be aligned in any of a plurality of predetermined directions.

3. A measuring system for a machine according to any of claims 1 or 2 wherein the complementary parts of the second mounting device comprises a set of cooperating elements on the base and the first housing and wherein  
5 a subset of cooperating elements used to align the first housing in a first direction also form a subset of cooperating elements used to align the first housing in a second direction.
- 10 4. A measuring system for a machine according to any preceding claim which the second housing is mounted onto the second surface of the machine via a connecting device and wherein a plurality of surfaces on the  
15 second housing and at least one surface on the connecting device are each provided with a complementary part of a third mounting device, such that the second housing may be attached to the connecting device when orientated in any of the plurality of predetermined directions.
- 20 5. A measuring system according to claim 4 in which the complementary parts of the third mounting device are arranged such that once the first and second housings have been aligned using the first mounting  
25 device, and the first housing and base have been aligned using the second mounting device, the second housing and the connecting device may be connected without realignment of the first and second housing relative to one another being required.
- 30 6. A measuring system according to any of claims 4 or 5 in which the geometric combination of the first and second housings and the connecting device is such that the axes along which the first and second housings may



be aligned intercept at a common point.

7. A measuring system according to claim 6 in which the geometric combination of the first and second housings is such that the housing mounted on a moving part of the machine starts in the same position in X,Y,Z, whatever the orientation of the first and second housings.
8. A measuring system according to claim 6 in which the geometric combination of the first and second housings is such that the housing mounted on a moving part of the machine is moved through the interception of the axes, whatever the orientation of the first and second housings.
9. A measuring system according to any preceding ~~claim wherein a cable leads to the first housing and~~ wherein the cable is provided with a cable mounting device, wherein at least one surface on the cable mounting device and a plurality of surfaces on the base are each provided with complementary parts of a fourth mounting device such that the cable mounting device may be mounted on the base at different locations such that at each orientation of the first housing, the cable transmits an equal force on the housing.
10. A measuring system according to claim 9 wherein the cable mounting device is provided with a plurality of angled faces, wherein two or more faces of the cable mounting device are provided with said complementary part of the fourth mounting device, such that different faces of the cable mounting device may be attached to the base for different orientations of the first

housing, such that the cable transmits an equal force on the housing for each orientation of the housing.

11. A measuring system according to any preceding  
5 claim in which the angle of the base is adjustable.

12. A platform for supporting a housing, the housing and platform being provided with complementary parts of a mounting device which define the position of the  
10 housing when mounted on the platform, comprising:  
a fixed surface of the platform on which the housing may be supported and on which part of said mounting device is located;  
a lifting mechanism moveable between upper and  
15 lower positions relative to said fixed surface;  
whereby in its lower position, the lifting mechanism allows the complementary parts of the mounting device of the housing and the fixed surface to be in contact with one another and in its upper  
20 position, the lifting mechanism causes the complementary parts of the mounting device of the housing and the fixed surface to at least partly break contact with one another.

25 13. A platform according to claim 12 wherein the lifting mechanism comprises a movable surface of the platform which may be raised and lowered;  
whereby when the housing is placed on the moveable surface of the platform, the moveable surface may be  
30 lowered to place the housing onto the fixed surface such that the complementary parts of the mounting device are connected or raised to disconnect the complementary parts of the mounting device.

14. A platform according to claim 13 wherein the movable surface and the housing are provided with complementary parts of a second mounting device such that the complementary parts of the first mounting  
5 device on the housing and first surface are thereby pre-aligned.

15. A platform according to any of claims 12 to 14 wherein rotation of the movable surface in a first  
10 direction causes said movable surface to be raised and wherein rotation of the movable surface in a second opposite direction causes said movable surface to be lowered.

15 16. A platform according to any of claims 12 to 14 wherein the movable surface is mounted on parallel springs whereby rotation of a cam raises or lowers the springs and thus the movable surface.

20 17. Apparatus for adjusting the angle of an object about an axis mounted on a surface comprising:  
an upper plate onto which the object is mounted  
and a lower plate which in turn is mounted onto the surface;  
25 a track located on the inner surface of one of the upper and lower plates;  
a ball located between the upper and lower plates, the ball being in contact with the at least one track in the upper or lower plates;  
30 wherein the track is arranged such that when the ball is moved in a first direction, the ball is raised and causes the plates to move apart and wherein when the ball is moved in a second opposite direction, the ball is lowered and causes the plates to move together.

18. Apparatus for adjusting the angle of an object according to claim 17 wherein the track comprises a pair of non-parallel rollers.
- 5 19. Apparatus for adjusting the angle of an object according to claim 17 wherein the track comprises a pair of parallel rollers which are positioned at an angle from the plane of the upper or lower plate in which they are located.
- 10 20. Apparatus for adjusting the angle of an object according to claim 17 wherein the track comprises a pair of rollers and wherein each roller in the pair of rollers is tapered.
- 15 21. Apparatus for adjusting the angle of an object according to any of claim 17-20 wherein the other of the upper and lower plates is provided with at least one element which is in contact with the ball.
- 20 22. Apparatus for adjusting the angle of an object according to claim 21 wherein the at least one element comprises a pair of parallel rollers.
- 25 23. Apparatus for adjusting the angle of an object according to claim 21 wherein the at least one element comprises a plane surface.
- 30 24. Apparatus for adjusting the angle of an object according to claim 21 wherein one of the at least one element and the track in the upper plate is part of a mount for the object and the other of the track and the at least one element of the lower plate is part of a mount for the surface, thereby forming a direct path

from the object to the surface through the tracks, balls and elements.

25. Apparatus for adjusting the angle of an object  
5 according to any of claims 17-24 wherein several sets of balls and tracks are provided so that the angle of the upper plate may be adjusted about several axes.

26. Apparatus for adjusting the angle of an object  
10 according to any of claims 17-25 wherein a track and ball is provided between adjacent substantially vertical surfaces of the upper and lower plates such that the upper plate may be rotated about the axis perpendicular to the plane of the lower plate.

15  
27. Apparatus for adjusting the angle of an object according to claim 26 wherein the apparatus is provided with at least two tracks and balls to adjust the angle of the upper plate relative to the plane of the lower  
20 plate and one track and ball to adjust the angle of the upper plate about the axis perpendicular to the plane of the lower plate, wherein the tracks used to adjust the angle of the upper plate relative to the plane of the lower plate are located in the lower plate so that  
25 during rotation of the upper plate, the elements in the upper plate may slide or rotate over the balls and thereby allow the upper plate to be rotated independently of the adjustment of the angle of the upper plate relative to the plane of the lower plate.

30  
28. Apparatus for adjusting the angle of an object according to claim 25 wherein two sets of tracks and rollers and a pivot may be provided to allow adjustment of the angle of the upper plate relative to the plane

of the lower plate.

29. Apparatus for adjusting the angle of an object according to claim 28 wherein a third set of tracks and  
5 rollers is provided to provide rotation of the upper plate about an axis perpendicular to the plane of the lower plate.

30. Apparatus for adjusting the angle of an object  
10 according to claim 25 wherein three sets of tracks and rollers may be provided to allow adjustment of the angle of the upper plate relative to the plane of the lower plate and in addition allow adjustment of the height of the upper plate relative to the lower plate.

15

31. Apparatus for adjusting the angle of an object according to claim 30 wherein a fourth set of tracks and rollers is provided to provide rotation of the  
upper plate about an axis perpendicular to the plane of  
20 the lower plate.

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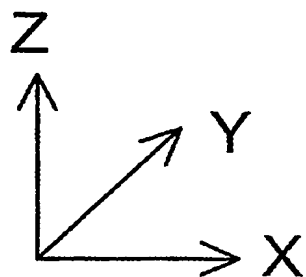
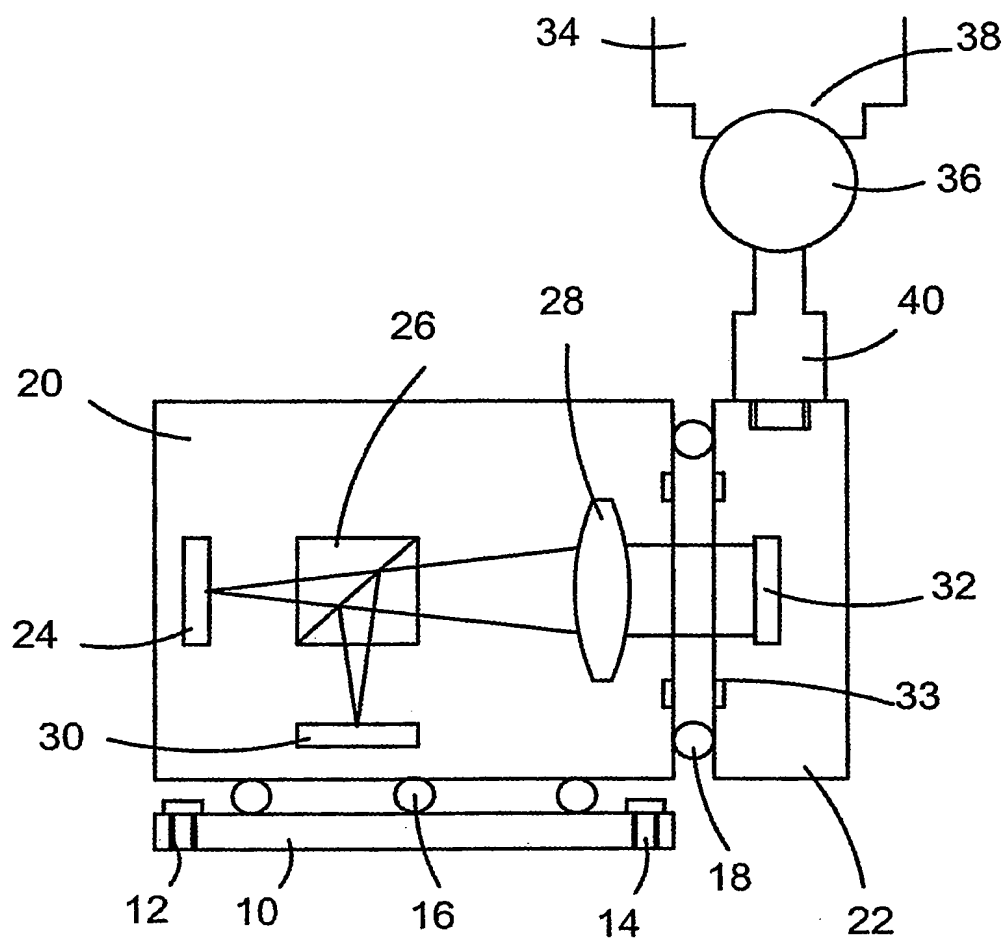


Fig 1 (PRIOR ART)

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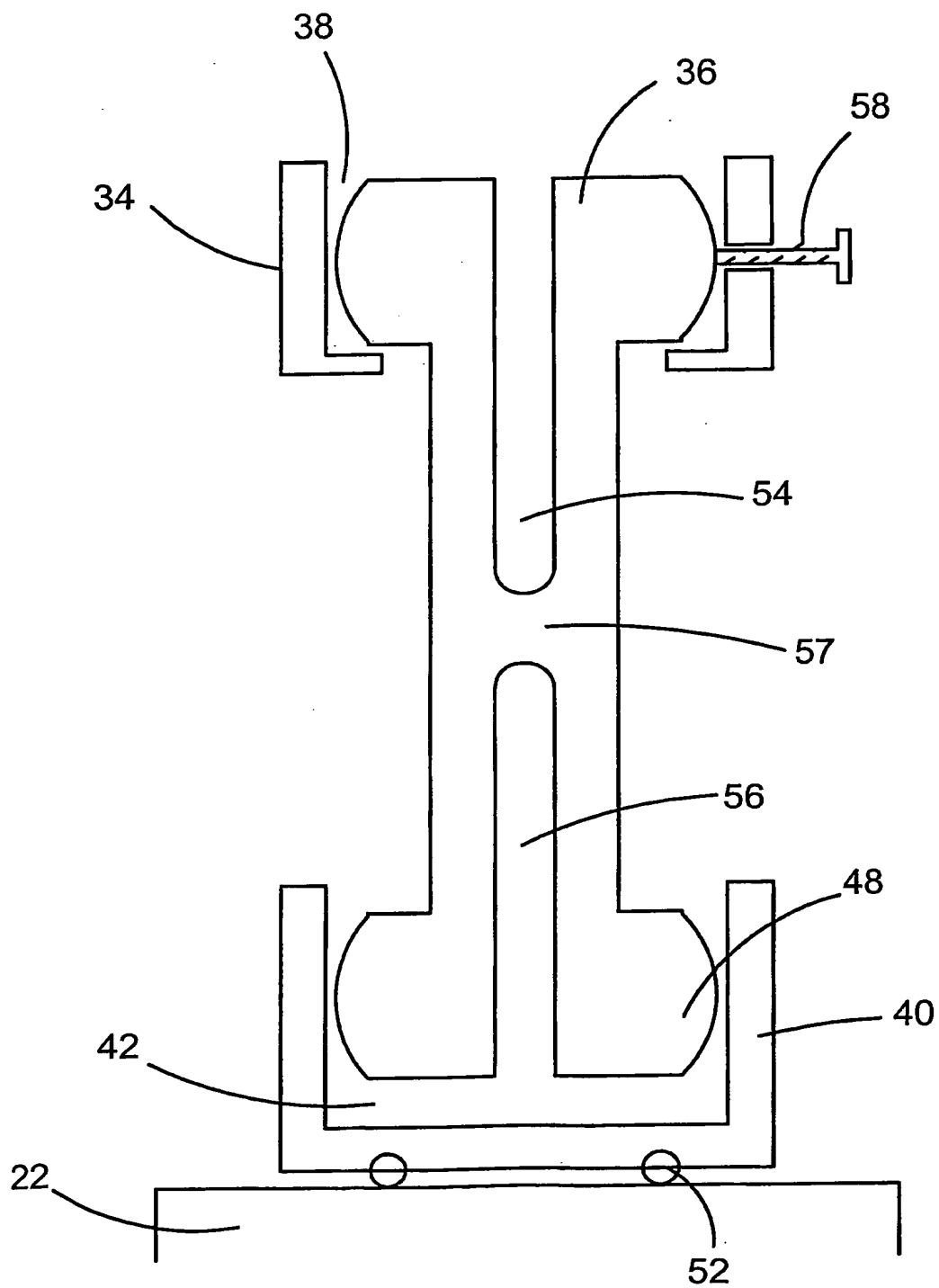


Fig 2



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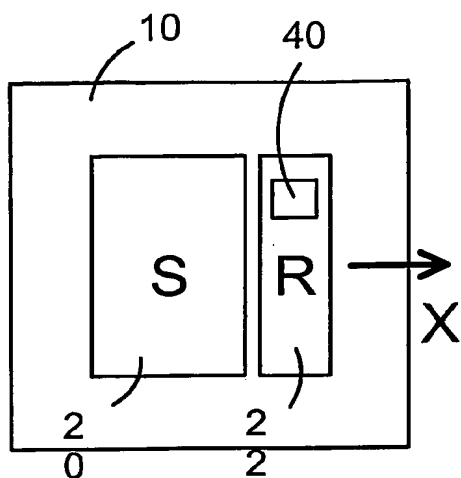


Fig 3A

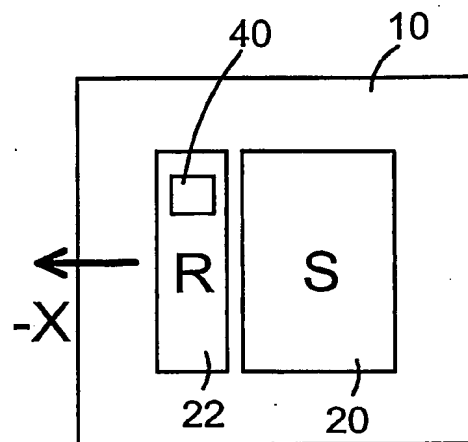


Fig 3B

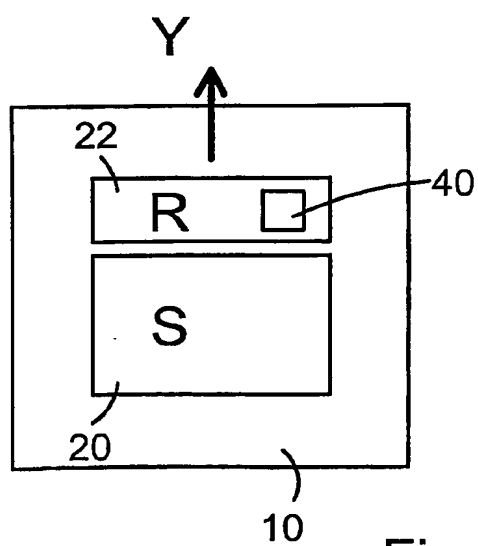


Fig 3C

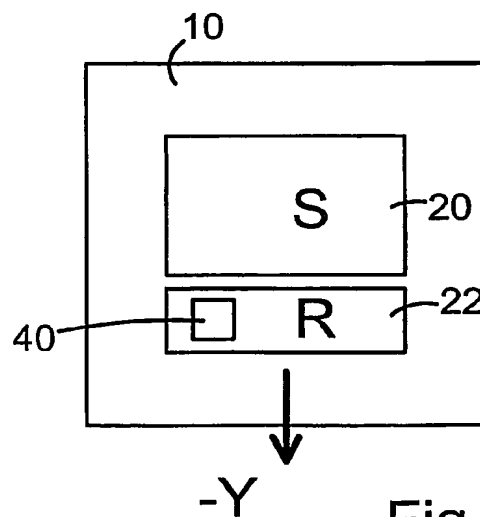
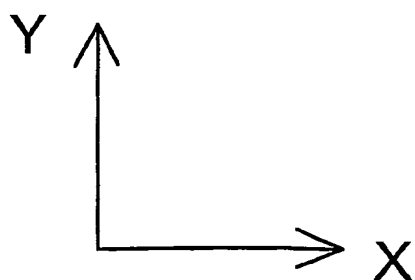


Fig 3D



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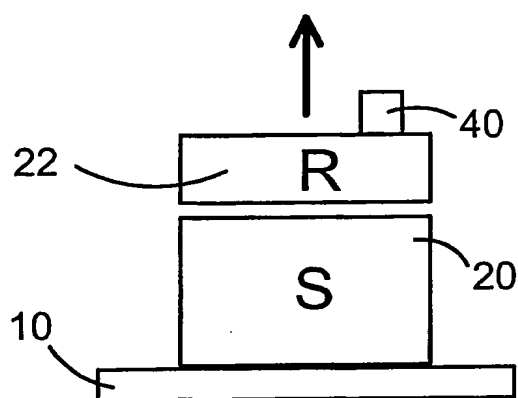


Fig 3E

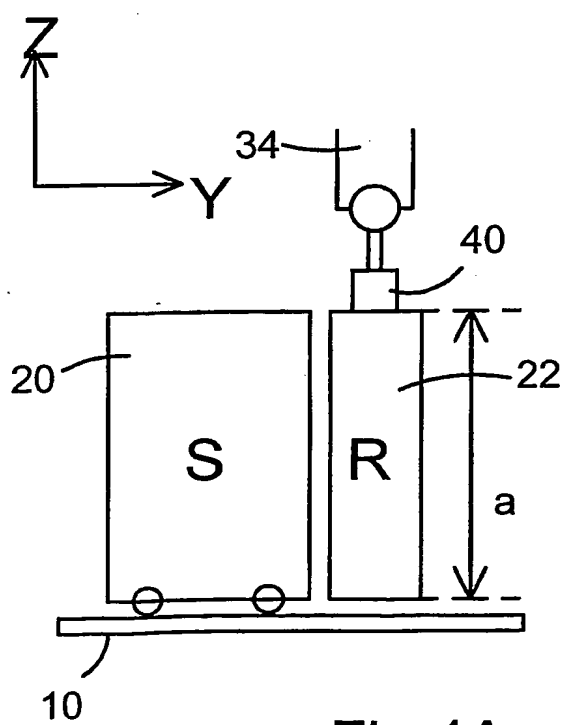


Fig 4A

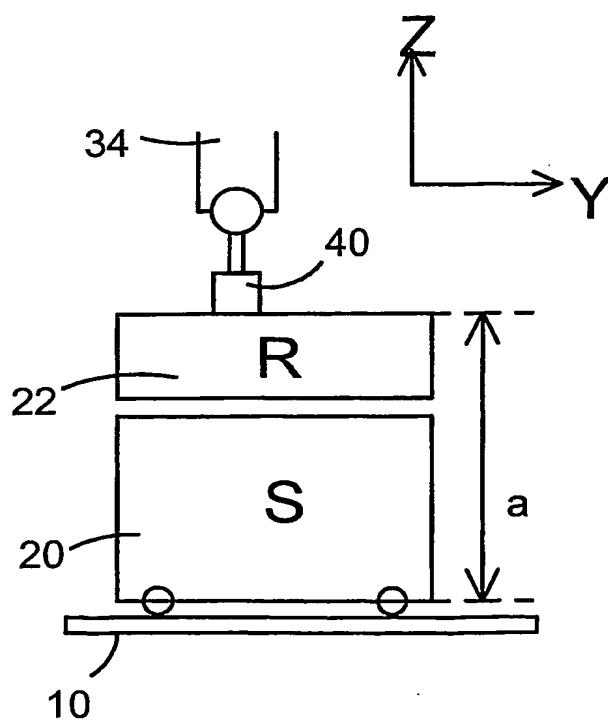


Fig 4B

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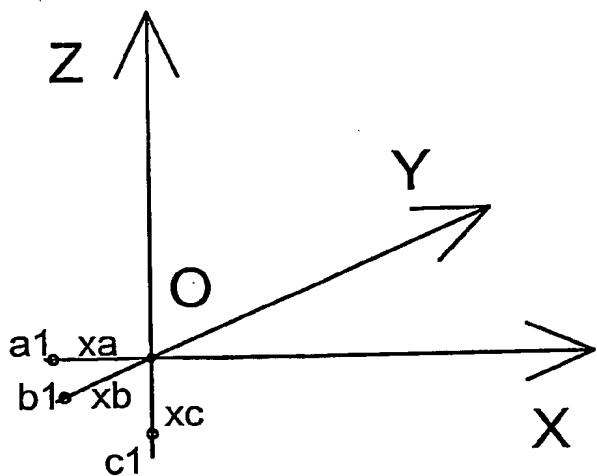


Fig 4C

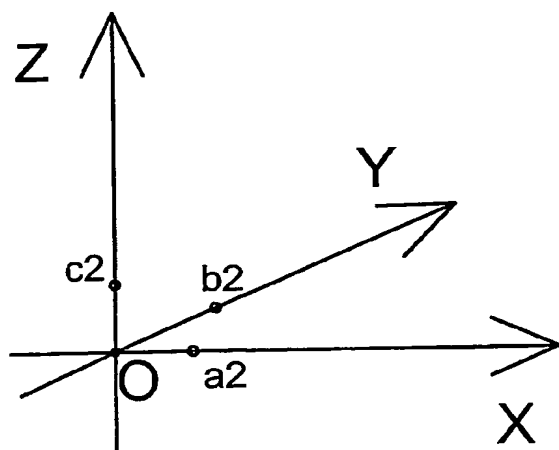


Fig 4D

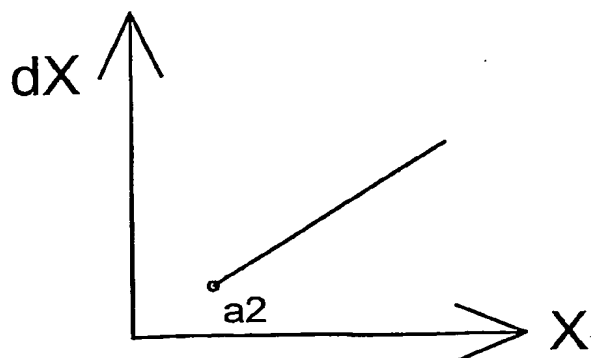
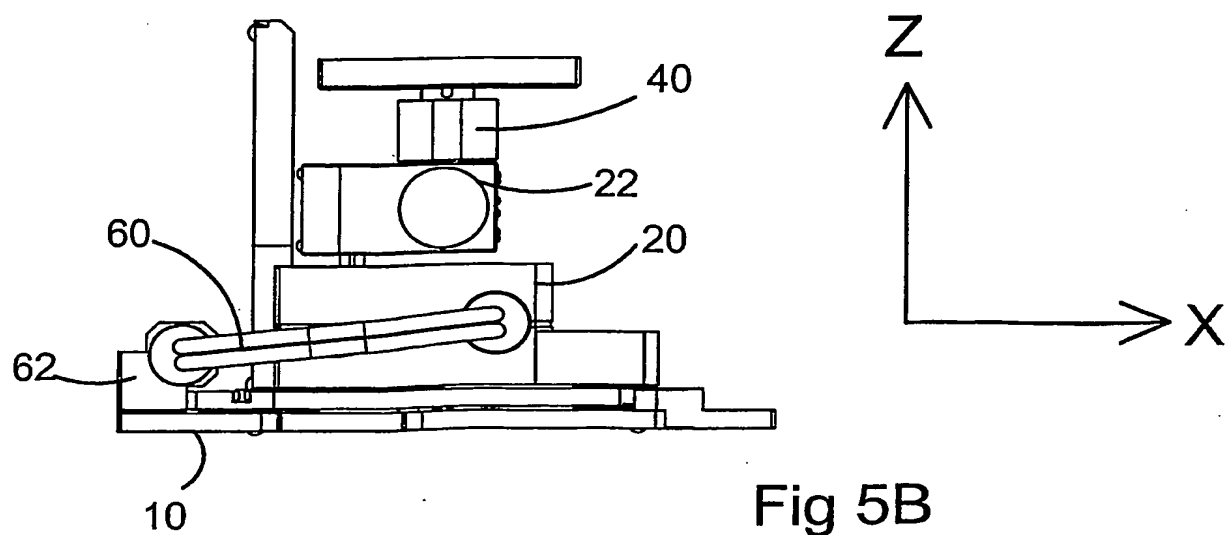
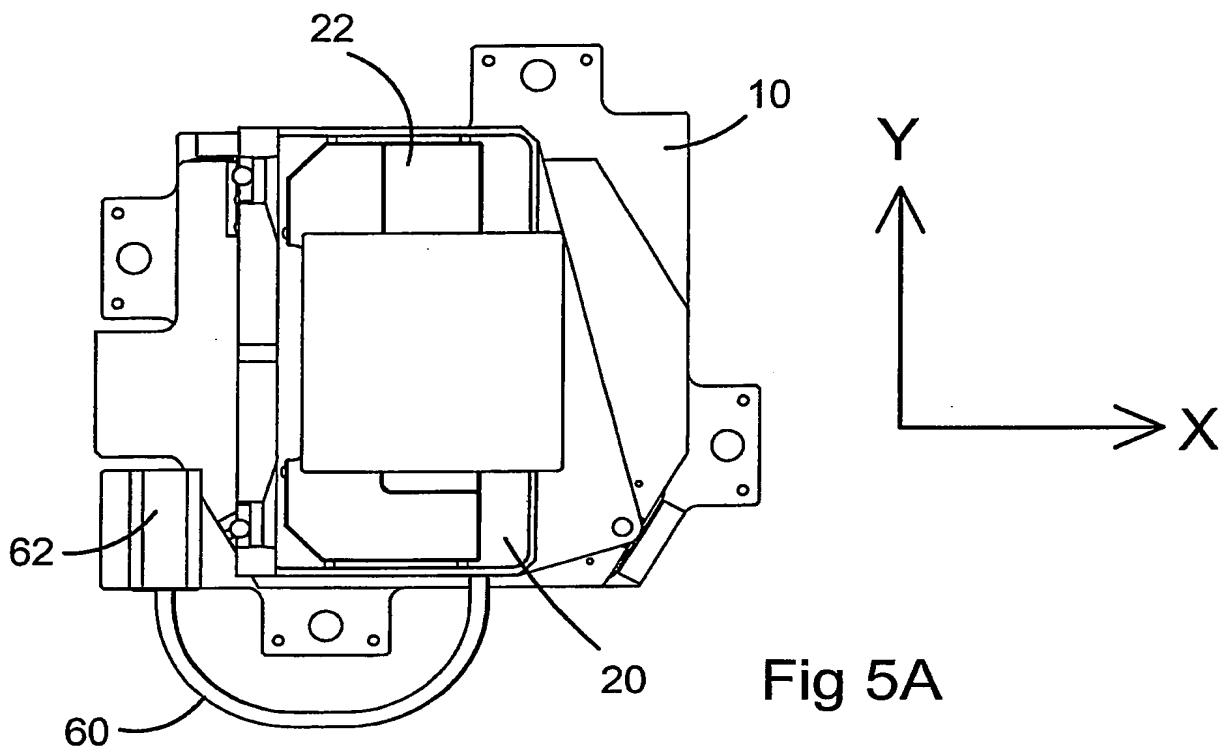
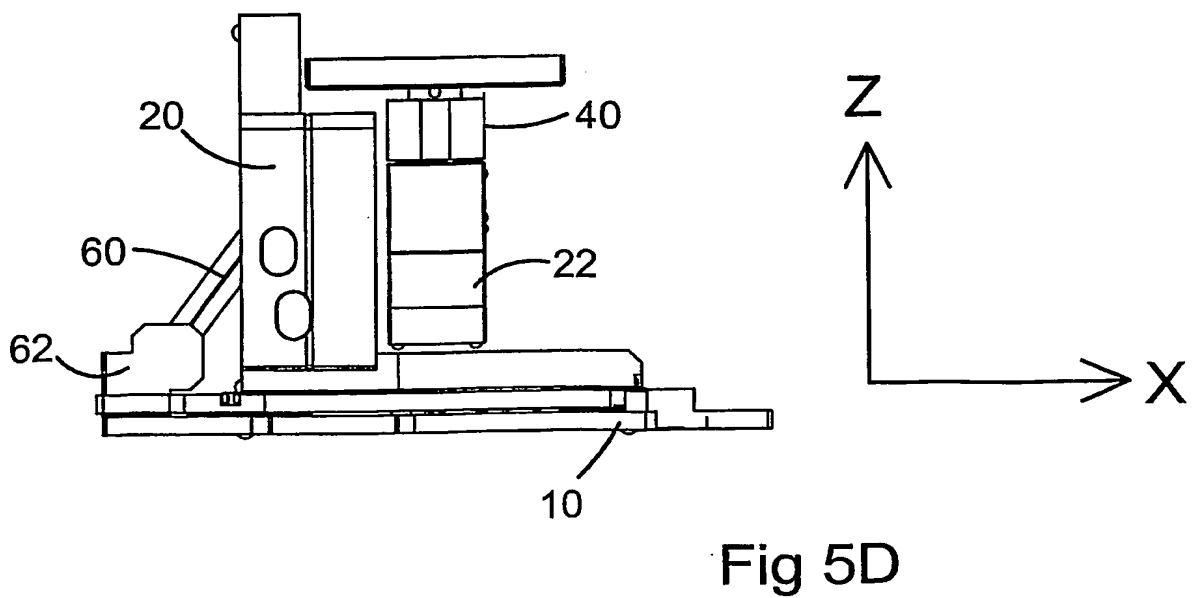
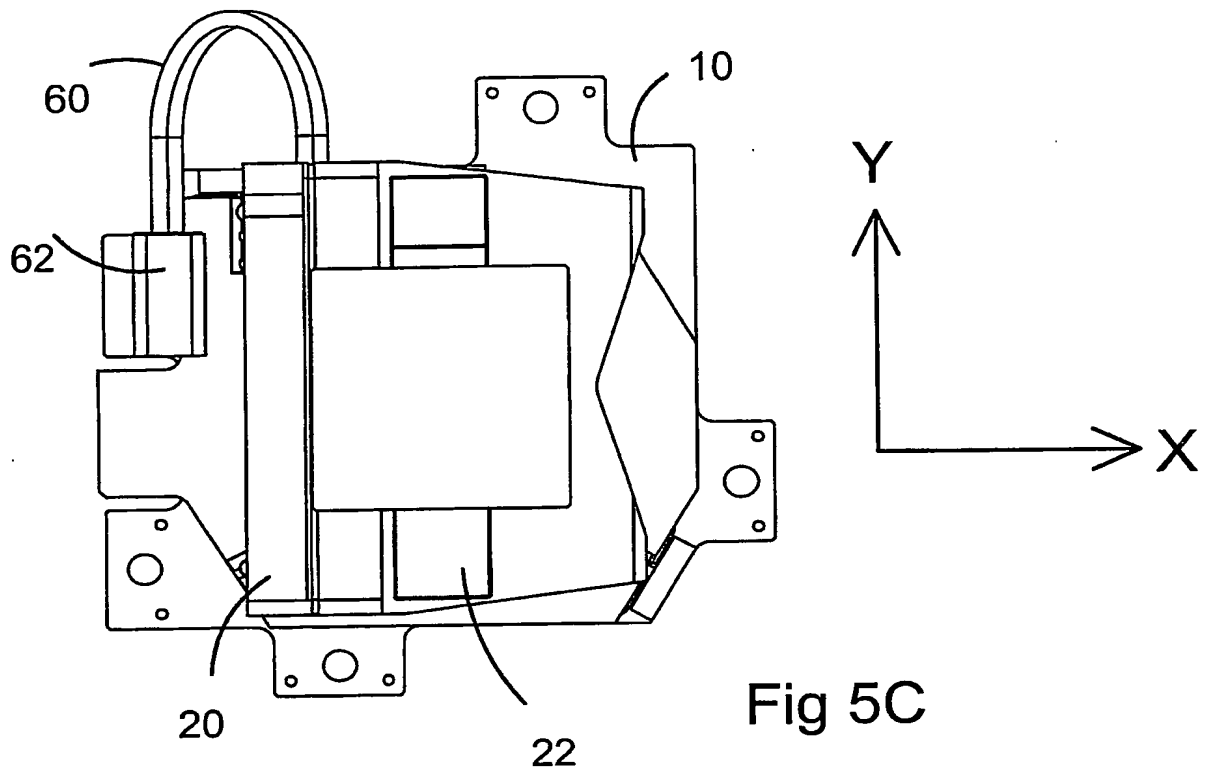


Fig 4E

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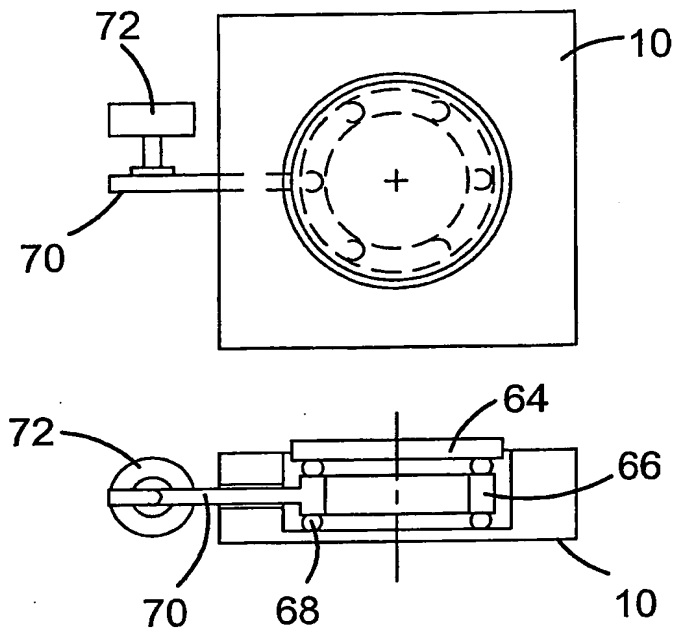


Fig 6A

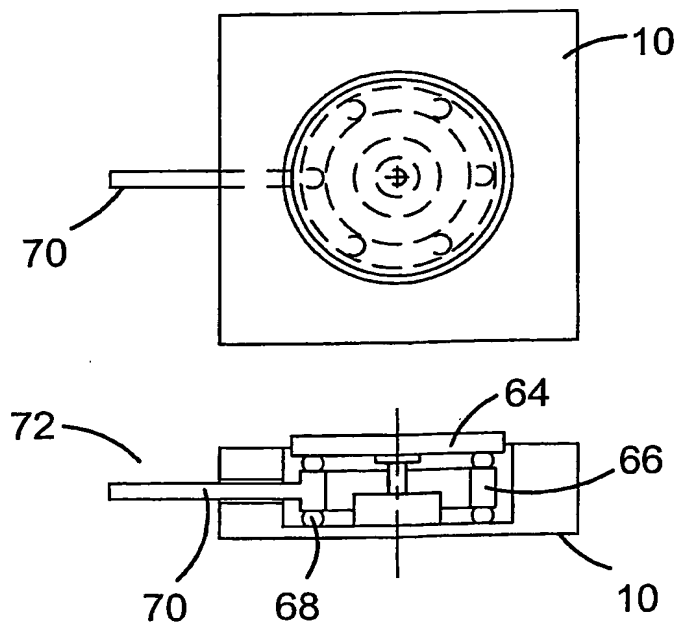


Fig 6B

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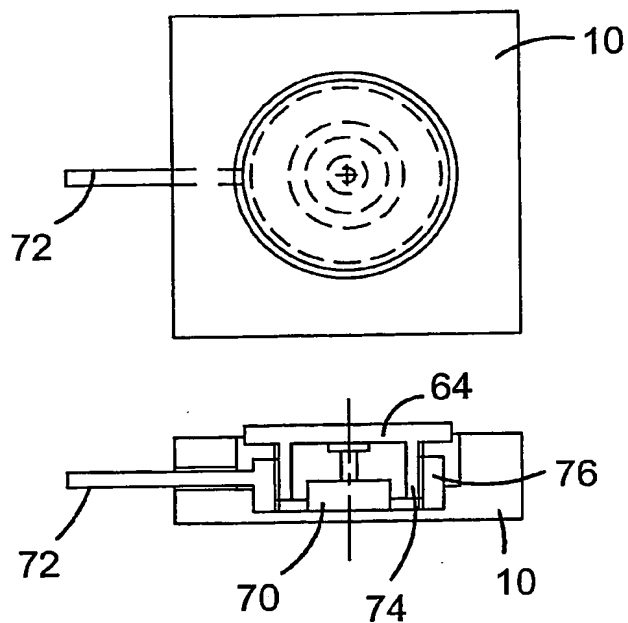


Fig 6C

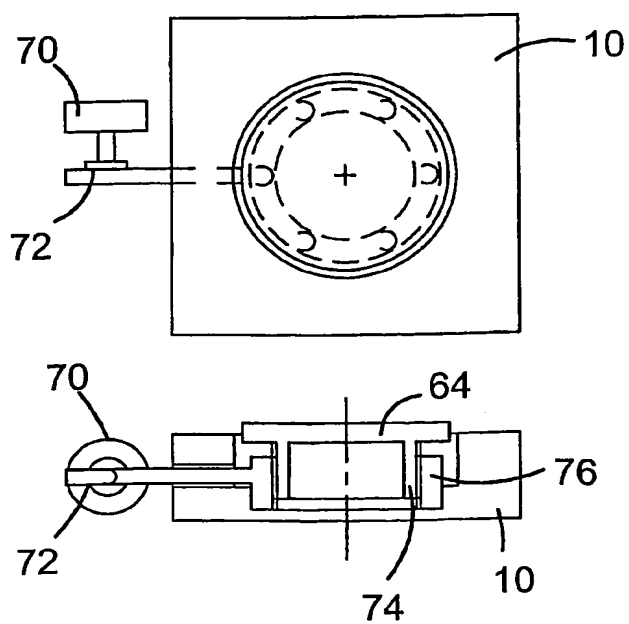


Fig 6D

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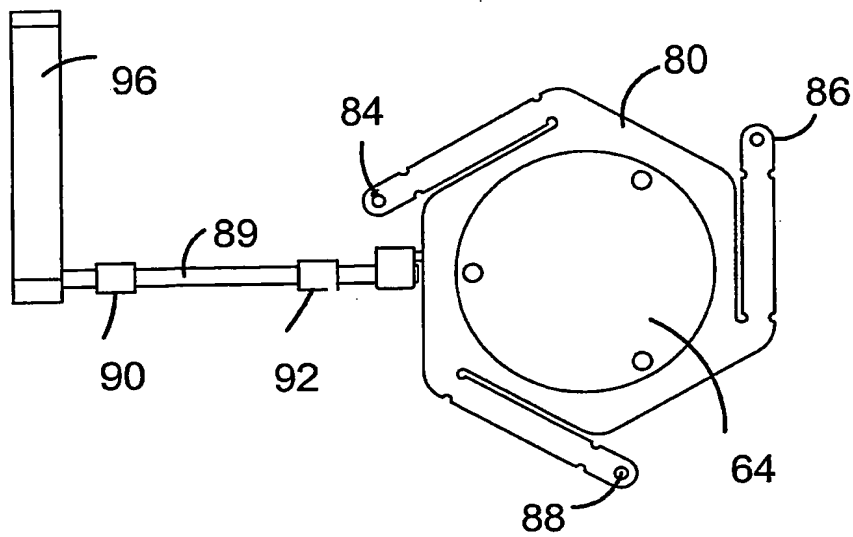


Fig 6E

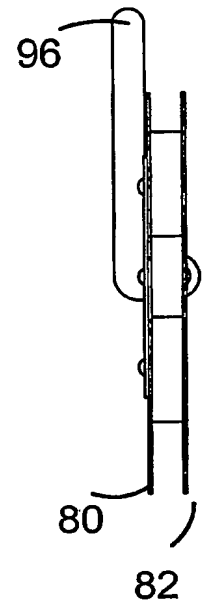


Fig 6F

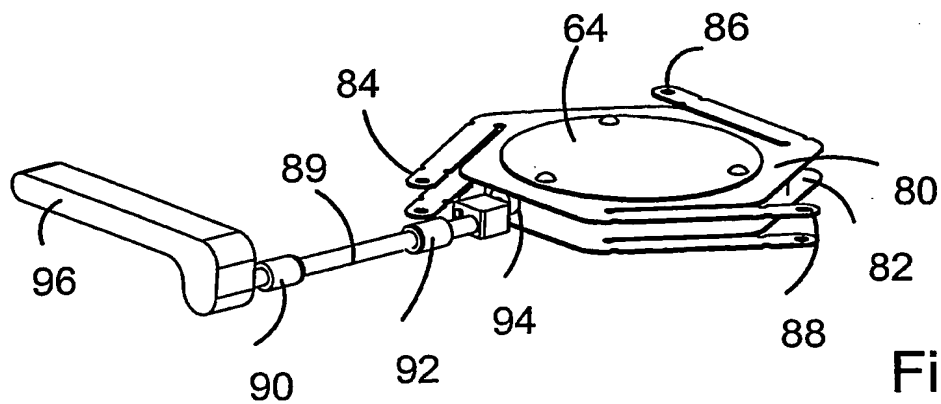


Fig 6G



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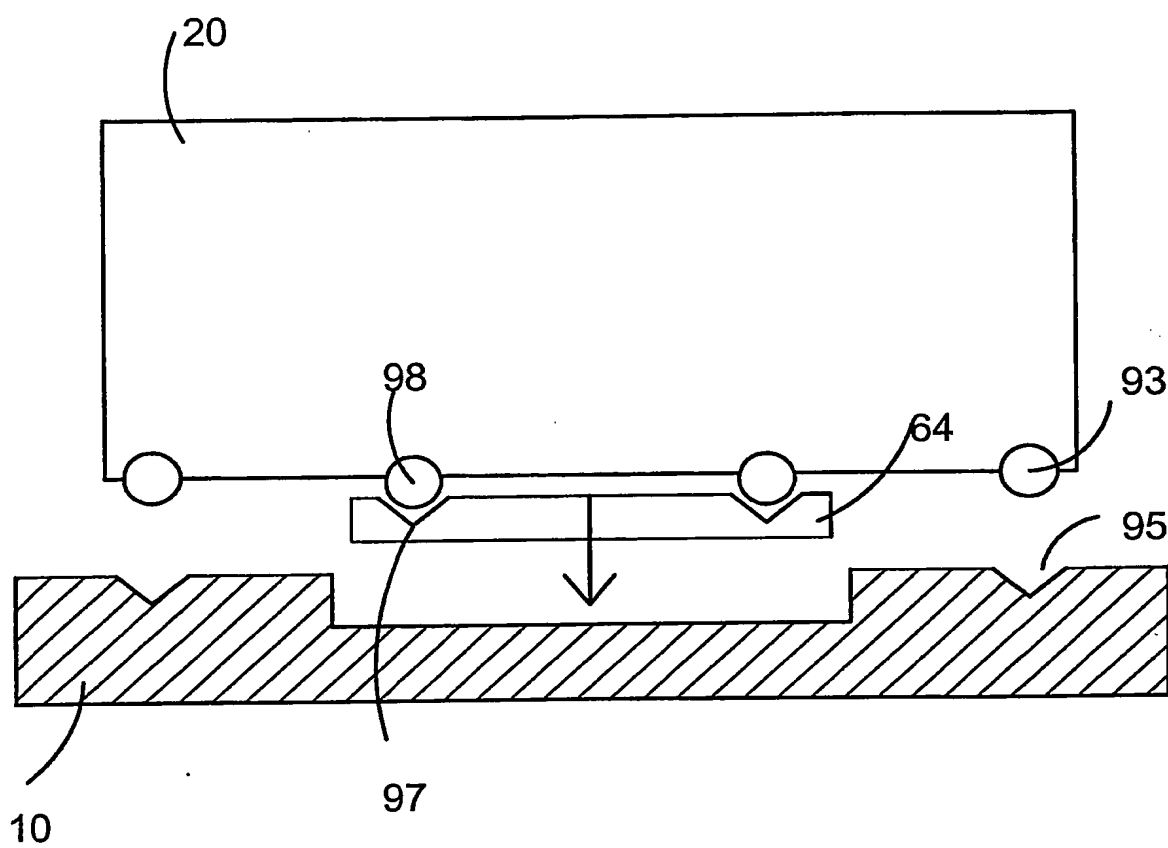


Fig 6H

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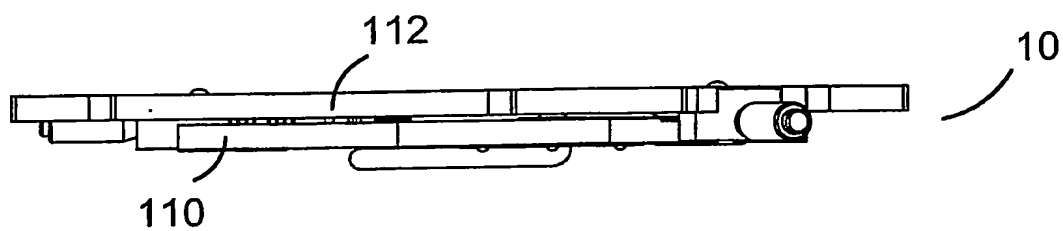
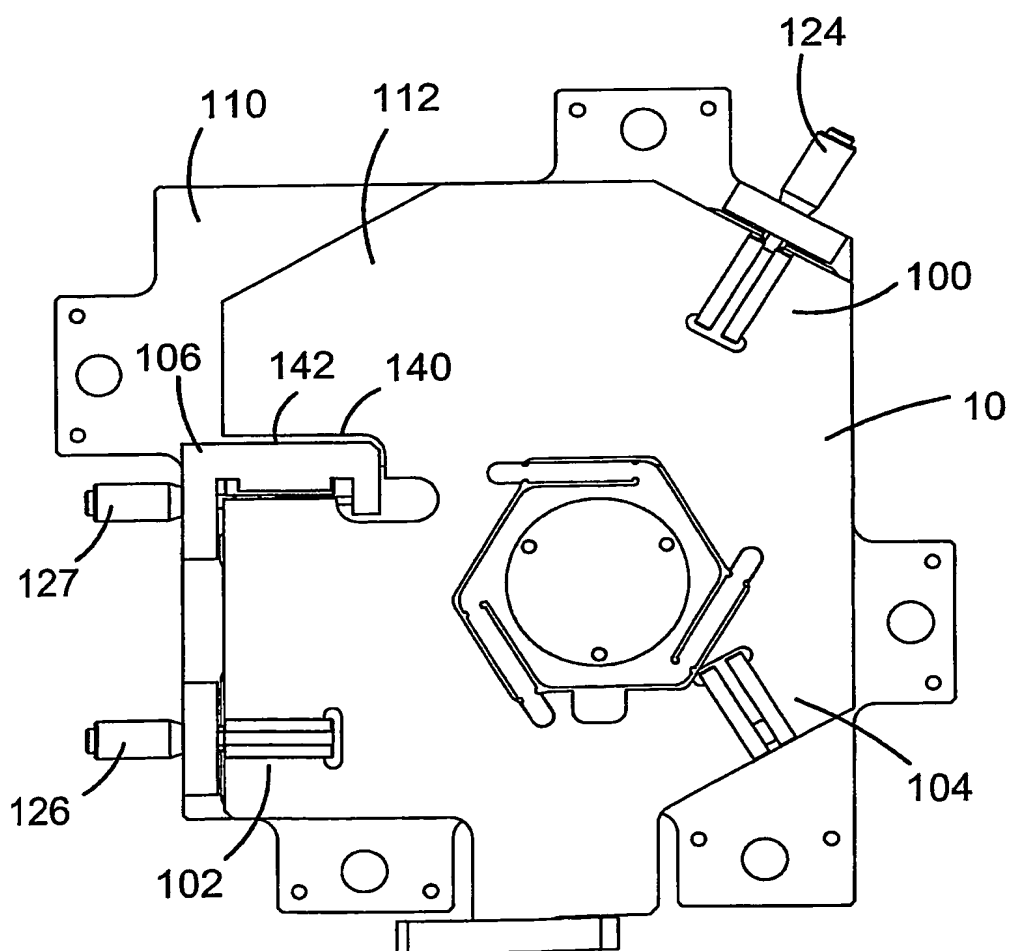


Fig 8



**Fig 7**

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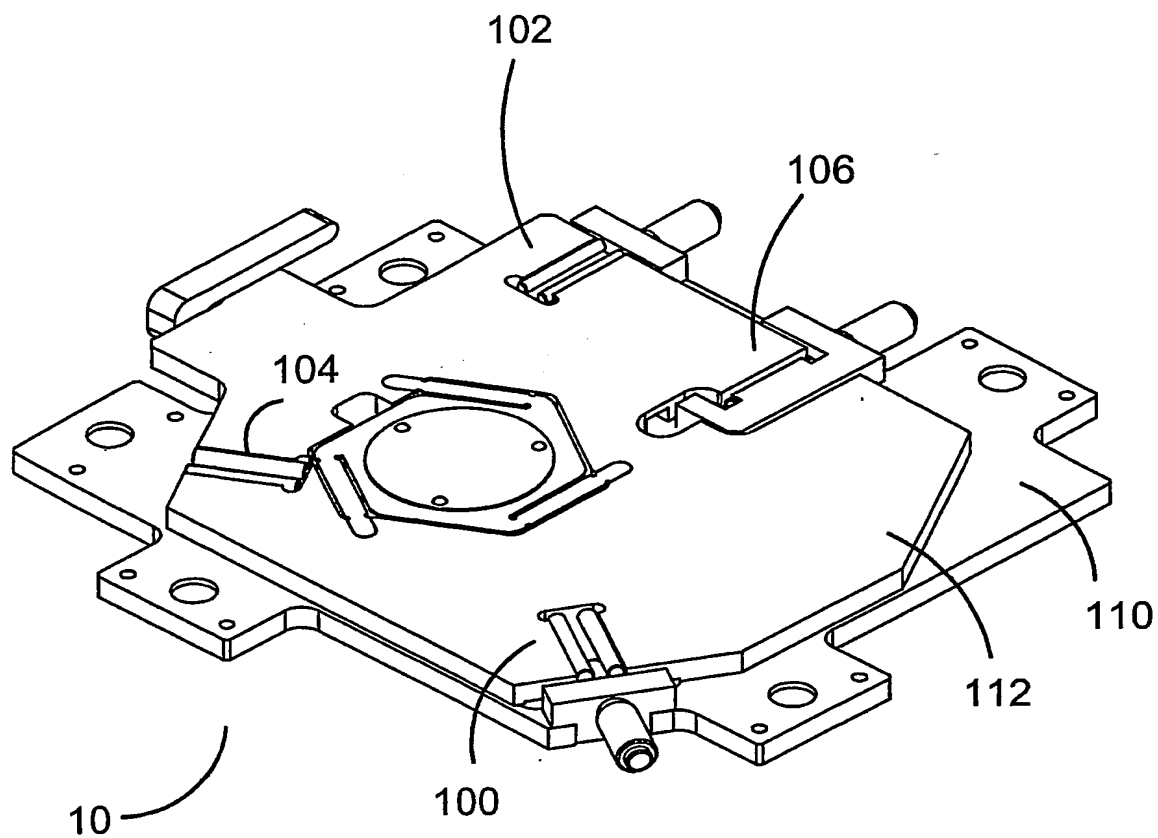


Fig 9



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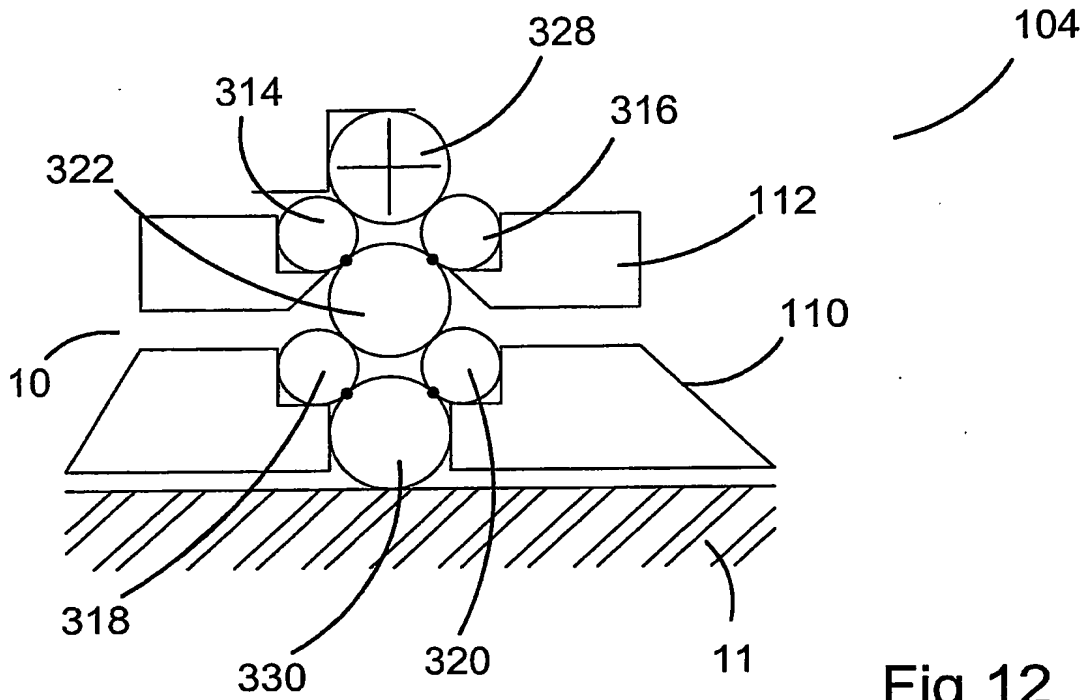


Fig 12

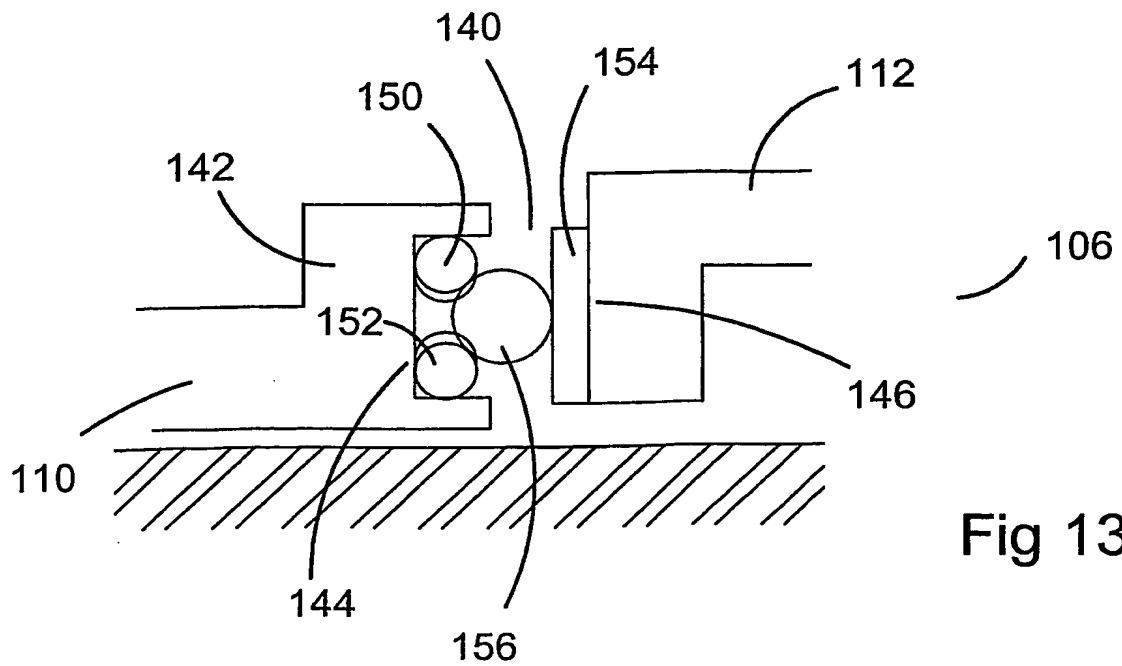


Fig 13

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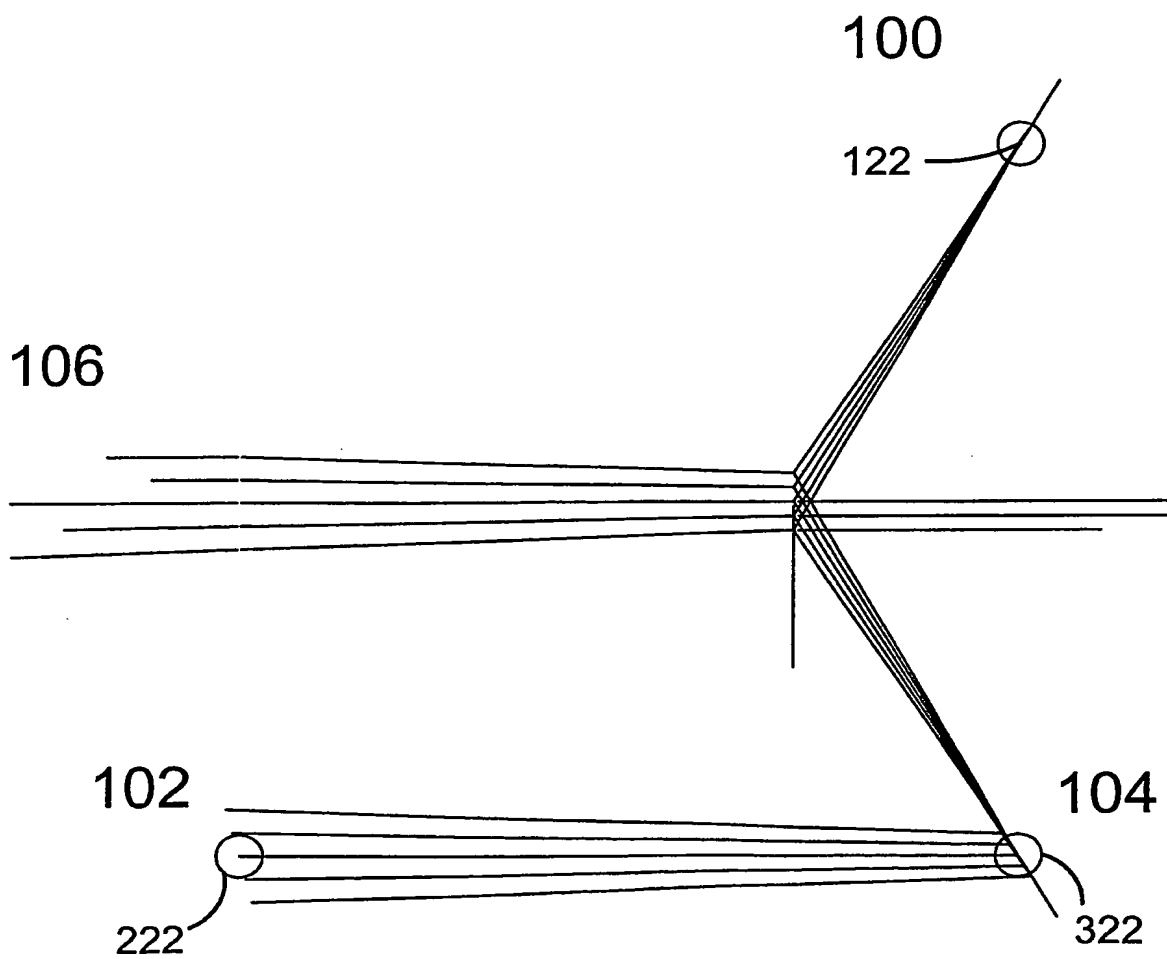


Fig 14

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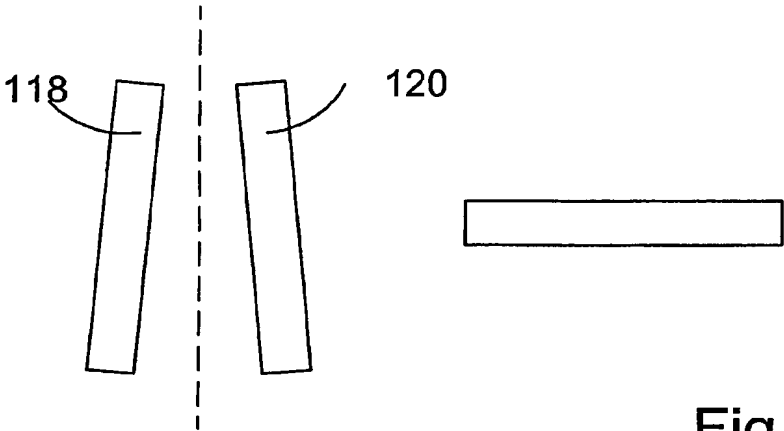


Fig 15

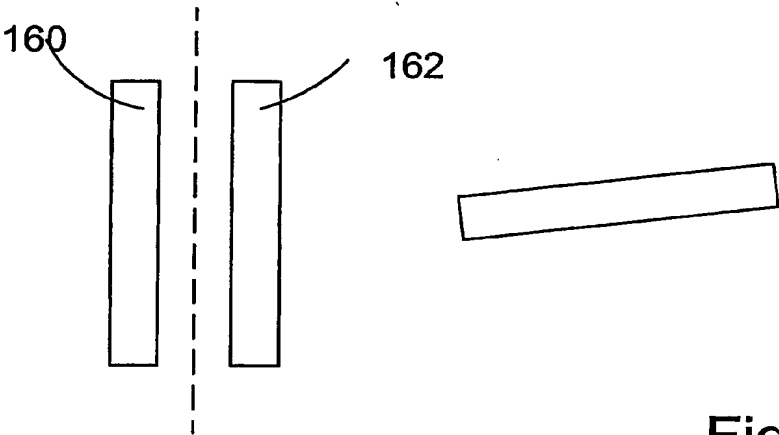


Fig 16

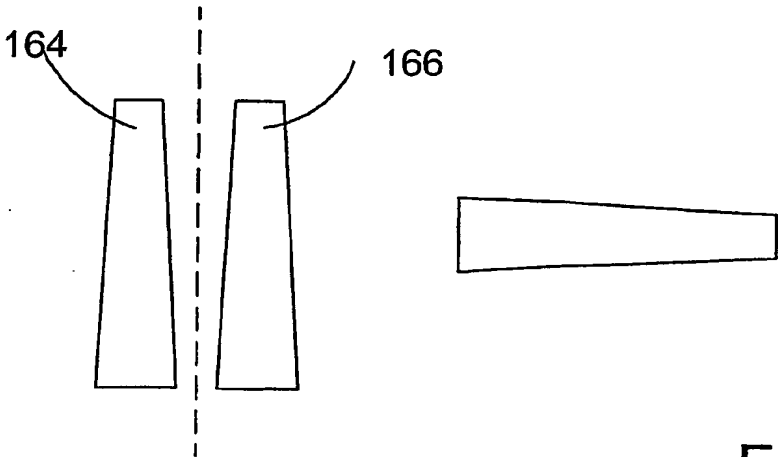
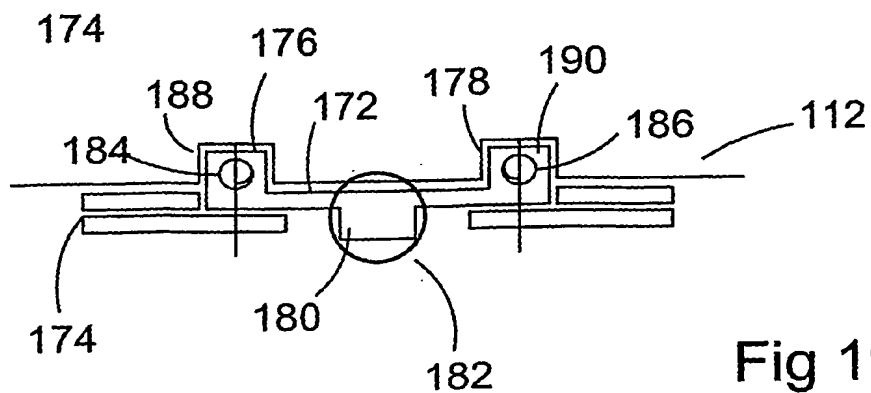
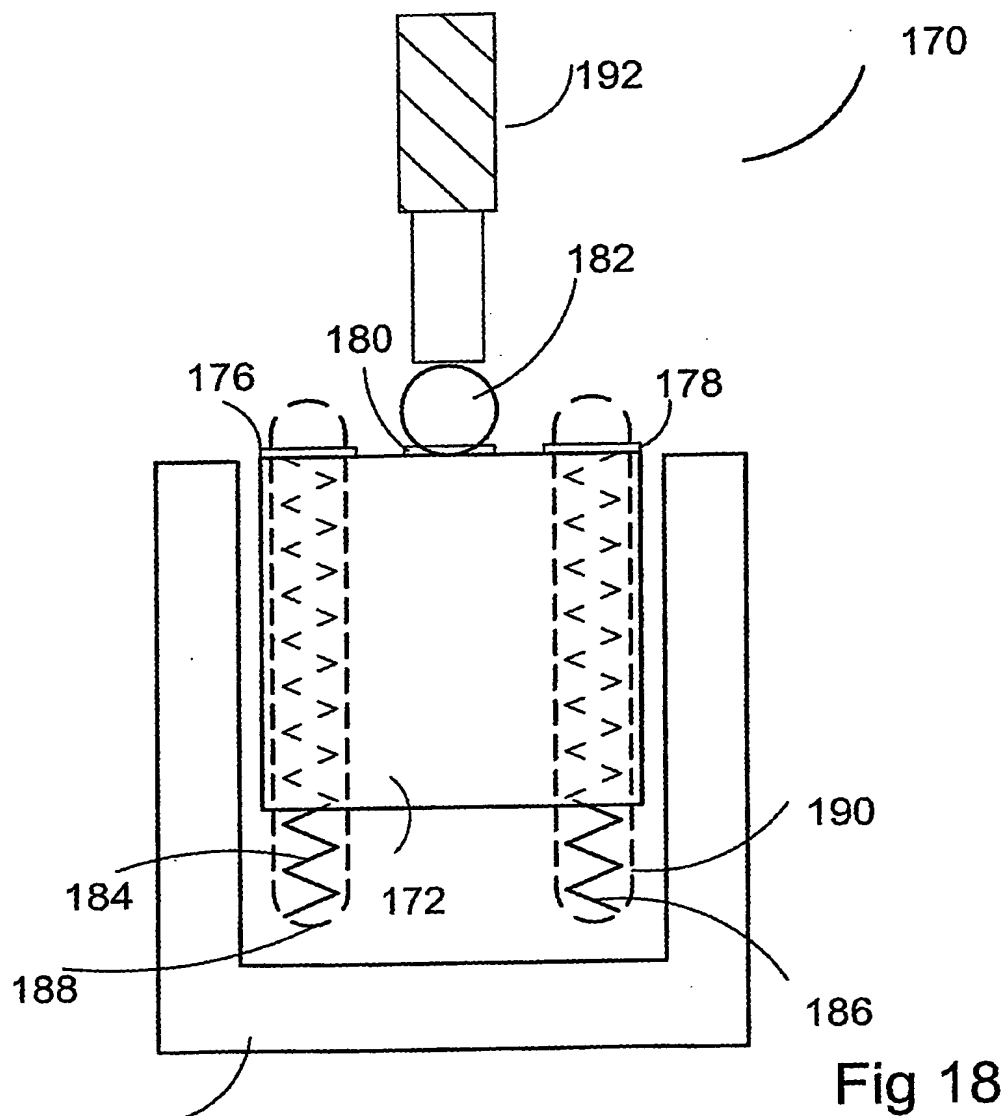


Fig 17

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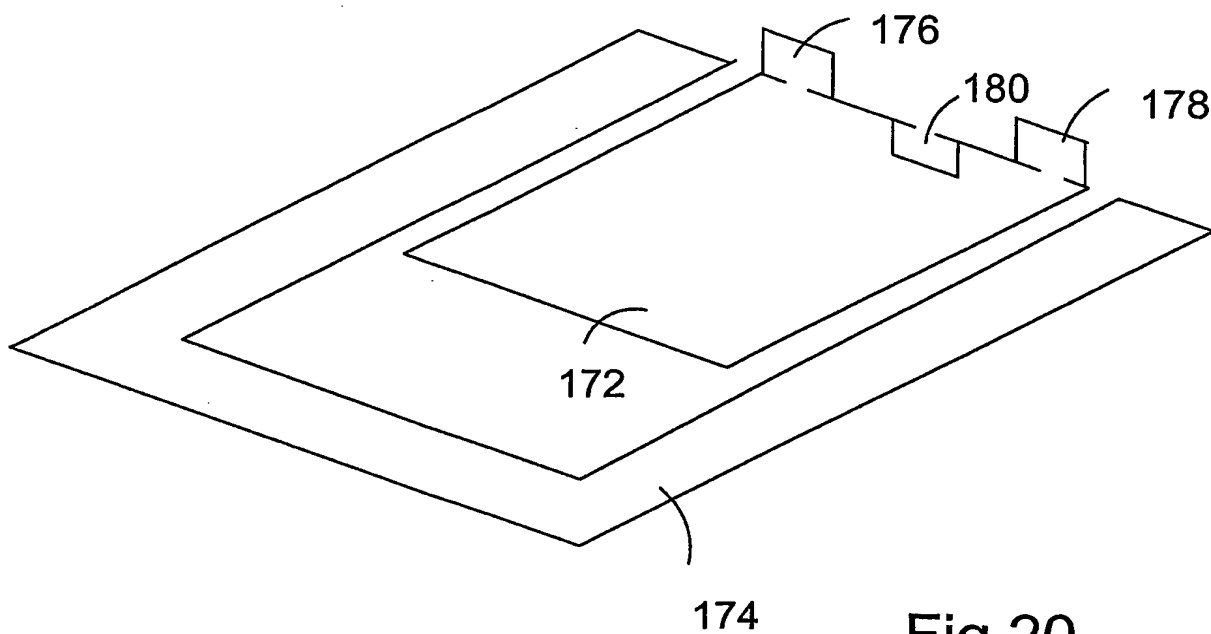


Fig 20

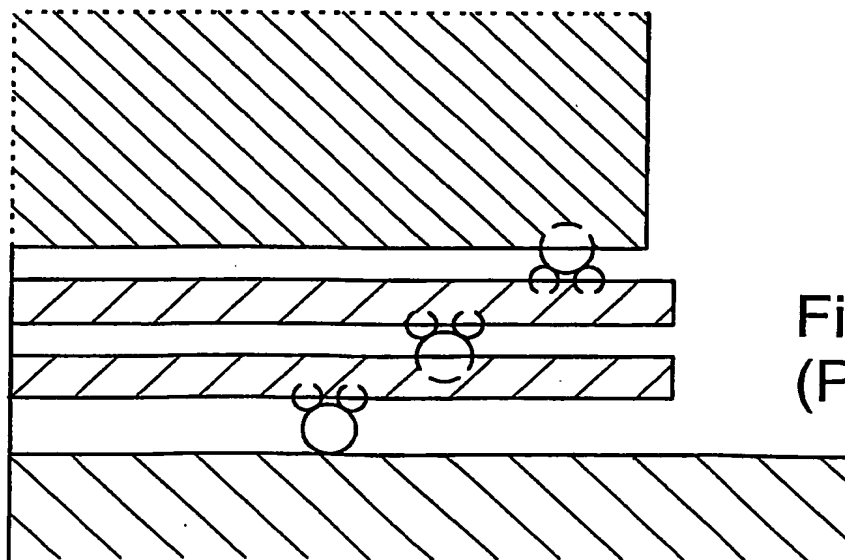


Fig 21  
(PRIOR ART)

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 03/00175

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC 7 G01B11/27 G02B7/00 F16M11/14 G01D11/30

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
 IPC 7 G01B B25J G02B F16M G01D G12B B23Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 939 678 A (BECKWITH JR WALTER L) 3 July 1990 (1990-07-03)	1
A	column 6, line 43 -column 7, line 58; figure 5	2-8
A	US 5 507 097 A (DUEY DAVID H ET AL) 16 April 1996 (1996-04-16)	1
A	column 5, line 14 -column 6, line 44; figures 1,4	
A	EP 0 529 182 A (HAMAR LASER INSTR INC) 3 March 1993 (1993-03-03)	1,9,10
A	column 17, line 28 -column 18, line 10; figures 2,5,16	
A	US 4 518 855 A (MALAK STEPHEN P) 21 May 1985 (1985-05-21)	1
	column 3, line 51 -column 4, line 20	
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

## \* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*G\* document member of the same patent family

Date of the actual completion of the international search

13 June 2003

Date of mailing of the international search report

- 1. 7. 03

Name and mailing address of the ISA

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Authorized officer

von Moers, F

# INTERNATIONAL SEARCH REPORT

Int'l Application No  
PC 1/GB 03/00175

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 159 989 A (CLAXTON GERALD L) 3 November 1992 (1992-11-03) column 2, line 20 - line 59; figures 1,2 ----	12
X	US 5 362 108 A (HRVATIN SCOTT) 8 November 1994 (1994-11-08) column 6, line 66 - column 7, line 36; figures 3,9 ----	12,13
Y		14
Y	US 4 278 381 A (BLOMQUIST ROBERT E ET AL) 14 July 1981 (1981-07-14) column 14, line 20 - line 68; figure 17 ----	14
X	US 4 925 288 A (HARRIS JOHN R) 15 May 1990 (1990-05-15) column 3, line 47 - line 59; figures 1-3 ----	17,19, 21-26,28
X	US 4 293 112 A (HORTON JAMES A) 6 October 1981 (1981-10-06) column 2, line 14 - line 43; figure 1 -----	17
A		26,27

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-8

Measuring system comprising a base and first housing mounted on a first part and second housings mounted on a second part of a machine. The adjacent surfaces of the base and the first housing and of the two housings have complementary parts that allow mutual alignment of these parts.

2. Claims: 9,10

Measuring system comprising a base and first housing and a cable mounting device

3. Claim : 11

Measuring system comprising a base and first housing wherein the angle of the base is adjustable

4. Claims: 12-16

Platform for supporting a housing with complementary mounting structures including a lifting mechanism for bringing the platform and housing in contact.

5. Claims: 17-31

Apparatus for adjusting the angle of an object relative to a surface, the apparatus comprising an upper plate for mounting the object, a lower plate mounted on the surface, and a track and a ball between the plates for performing the adjustment.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/GB 03/00175

### Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

### Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this International application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:  
1-10, 12-31
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

 Inte I Application No  
 PCT/GB 03/00175

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